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THE ROYAL ENGINEERS
FIELD-SERVICE POCKET-BOOK.

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BY

LIEUT.-COL. G. K. SCOTT-MONCRIEFF,
ROYAL ENGINEERS.

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1916
WAR OFFICE

SECOND EDITION.

EDITED BY

CAPT. R. F. EDWARDS, ROYAL ENGINEERS,
Secretary, R.E. Institute.

THIRD EDITION.

EDITED BY

MAJOR W. J. JOHNSTON, ROYAL ENGINEERS,
Chief Instructor in Surveying, S.M.E., Chatham.

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PREFACE TO FIRST EDITION.

SOME explanation is necessary for the publication of another pocket-book for the use of military engineers. It has not been compiled with the view of superseding those which have hitherto been published, but it attempts to supply a want which has long existed, viz., of having in one small volume the cream of the information contained in the official text-books on field engineering. Engineer officers in recent campaigns have either had to carry with them the whole of those text-books—a serious matter where the weight of luggage is limited—or they have had to trust to their own memories, which can hardly be expected to be always trustworthy.

The difficulty in compiling such a pocket-book has been to know what to omit, so as to bring the book within a reasonably small compass. The principles which have guided the compilation of this little work have been, first, to omit all drills; second, to omit long explanations of principles; third, to omit all lists of warlike stores and materials; and fourth, to include only those salient points in various operations which experience has shown to be of most importance.

The greater part of the book is taken up with field

engineering, based upon the S.M.E. official publications; there are, however, certain sections which are not included under this head. Such is Section I., which gives General Rules and Tables; Section X., dealing with Transport; Sections XI., XII. and XIII., dealing with Telegraphy, Survey, and Astronomy; Sections XIV. and XV., dealing with Medical and Veterinary matters respectively. No apology, I think, is necessary for the introduction of these subjects, the importance of which to the pioneers of an army is sufficiently patent.

The special subjects of Ballooning, Steam Machinery, Submarine Mining, and Electric Lighting have been omitted. It is certain that, if required in the field, such work would be entrusted to specialists.

I have to thank many of my brother officers for advice and assistance in the preparation of this little book. Several of the sections have been entirely written by other pens than mine. Captain W. A. Gale has not only in his capacity of Secretary of the R.E. Institute given me all assistance in printing, etc., but has, together with Captain Haynes, completely written the sections on Survey and Astronomy, as well as part of Section I. Lieut. Godfrey-Faussett has kindly written the section on Telegraphy. Surgeon-Major Cottell, A.M.S., has written the valuable section on First Aids to the Sick and Wounded, while Veterinary-Captain F. Smith, late Professor at the Army Veterinary School, has kindly revised Section XV., which was written by me from notes of lectures delivered by him and Veterinary-Captain Rutherford.

While thanking these officers especially, I also beg to acknowledge very gratefully the help given by Colonel Elliott Wood, C.B., Major Kenyon, Captains A. E. Haynes and Walton, and Lieut. Leggett.

The useful appendix on Railways, by Lieut. Leggett, was not received by me in time to print with the rest of the section on Railways.

I gratefully acknowledge the assistance afforded by other hand-books, such as General Cooke's *R.E. Aide Memoire*, Molesworth's *Pocket-book*, and Trautwine's *Civil Engineer's Pocket-book*.

I venture to express a hope that this little book, though written for the Royal Engineers, may contain some matter which may be useful to other branches of the army, and possibly to some of our brethren of the civil engineering profession (to which we, as a Corps, are so much indebted), who have to carry out pioneering operations in the colonies, or other distant parts of the world.

G. K. Scott-Moncrieff, *Major, R.E.*

Chatham,
June, 1894.

PREFACE TO THE SECOND EDITION.

In this edition certain alterations, founded for the most part on the experience of recent campaigns, have been introduced. Of these, the most important are in the section on Railways, in which the assistance given by Lieutenants Mahon, Chaldecott, and Turner, R.E., is gratefully acknowledged.

G. K. Scott-Moncrieff,
Lieut.-Colonel, R.E.

PREFACE TO THE THIRD EDITION.

On account of the very large numbers of newly commissioned officers, the demand for copies of *R.E. Field Service Pocket-Book* has been so great that a further edition has been necessitated.

This edition has been prepared on the supposition that officers employed in advance positions at the Front will not always have at their immediate disposal the larger works dealing with the science of military engineering. They are, however, supposed to carry their official *F.S. Pocket-Book*, and the scope of this book has been limited to embrace subjects which are not so fully dealt with in the official publication. A certain amount of redundancy is inevitable, but the carrying of these two pocket books does away with the necessity of republishing certain sections which appeared in the second edition.

For this reason the section on "Attack" has been omitted, as this is largely a tactical question, and is fully dealt with in the *F.S. Pocket-Book*. Similarly Sections XIV. and XV. in the second edition, dealing with "First Aid" and "Veterinary Notes," and the portion of Section XII. dealing with "Reconnaissance" have been left out.

The section on "Field Telegraphy" is being rewritten, but owing to pressure of work, it has not yet been completed, and it is deemed desirable not to delay the rest of the work. It is hoped, however, that this section, which, owing to the great changes in signal organization since 1900, is bound to be of especial interest to a large number of officers of the Corps, will be published and issued separately.

Owing to the constant changes taking place in Field Defences it has been decided, after consultation with the officers closely connected with the subject, to omit this section, which will be rewritten after the War and issued to all subscribers. Blank pages have been inserted to enable officers to insert their own personal notes on the subject.

As the compiler of the first and second editions is now occupied with duties, which take up his whole time otherwise, the revision of this edition has been entrusted, with the concurrence of the Commandant, S.M.E., to Major W. J. JOHNSTON, R.E.

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SECTION I.

GENERAL RULES AND TABLES.

WEIGHTS AND MEASURES.

BRITISH.

With Metric Equivalents.

(Also used in the United States).

Troy Weight.

1 grain (British unit of Weight)	=	0·065 gme.
1 dwt. = 24 grs.	=	1·55 ,,
1 oz. = 20 dwt. = 480 grs.	=	31·10 ,,
1 lb. = 12 ozs. = 240 dwt. = 5760 grs.	=	373·24 ,,

Avoirdupois Weight.

1 dr.	=	1·77 gme.
1 oz. = 16 drs.	=	28·35 ,,
1 lb. = 16 ozs. = 256 drs.	=	0·45 kilogme.
1 qr. = 28 lbs. = 448 ozs. = 7168 drs.	=	12·7 ,,
1 cwt. = 4 qrs. = 112 lbs. = 1792 ozs.	=	50·8 ,,
1 ton = 20 cwt. = 80 qrs. = 2240 lbs.	=	1·016 millier.

1lb. = 7000 grains ; 14lbs. = 1 stone ; 36lbs. of straw, or 56lbs. of hay (old), or 60lbs. of hay (new), make a *truss*. 36 trusses = 1 load, or 18cwt. of hay (old).

In the United States, 1 quintal = 100lbs.

Linear Measure (for General Purposes).

1 in.	=	0·25 decimètre.
1 ft. = 12 in.	=	3·048 ,,
1 yd. = 3 ft. = 36 in.	=	0·914 mètre.
1 furl. = 220 yds. = 660 ft. = 7920 in.	=	201·166 ,,
1 mile = 8 furl. = 1760 yds. = 5280 ft.	=	1·609 kilom.

Linear Measure (used in Surveying).

1 link = 7·92 in. = 0·201 mètre.
1 pole = 25 links = 198 in. = 5·029 ,,
1 chain = 4 poles = 100 links = 792 in. = 20·117 ,,
1 furl. = 10 chains = 40 poles = 1000 links = 201·166 ,,
1 mile = 8 furl. = 80 chains = 320 poles = 1·609 kilom.

1 geographical mile = 1·152 statute miles = 6082·66ft.; 60 geographical miles = 1 degree at the equator; 1 fathom = 6ft.; a cable's length = 120 fathoms = 240yds.; 1 Admiralty knot or nautical mile = 6080ft.; 1 league = 3 nautical miles.

Scotch mile = 1974 yards = 1·12159 English miles.
Irish ,, = 2240 ,, = 1·27273 ,, ,,

Superficial Measure.

1 sq. in. = 0·0006 sq. mètre.
1 sq. ft. = 144 sq. in. = 0·093 ,,
1 sq. yd. = 9 sq. ft. = 1296 sq. in. = 0·836 ,,

1 sq. pole or perch	= 30¼ sq. yds.	= 272¼ sq. ft.	= 39204 sq. in.	= 0·253 are or sq. decamèt.
1 rood	= 40 poles	= 1210 sq. yds.	= 10890 sq. ft.	= 10·117 ,, ,,
1 acre	= 4 roods	= 160 poles	= 4840 sq. yds.	= 0·405 hect. or sq. hectomèt.
1 sq. mile	= 640 acres	= 2560 roods.	= 3097600 sq. yds.	= 258·9941 hectare.

Scotch acre = 6150·4 sq. yds. = 1·27074 Eng. acres.
Irish ,, = 7840 ,, = 1·61983 ,,
36 sq. yds. brickwork = 1 rod; 10 sq. chains = 1 acre.

Cubic Measure.

1 cub. in. = 0·000016 cub. mètre.
1 cub. ft. = 1728 cub. in. = 0·028 ,, ,,
1 cub. yd. = 27 cub. ft. = 46656 cub. in. = 0·764 ,, ,,

40ft. of rough or 50ft. of hewn timber = 1 load.

Capacity.

1 gill = 0·142 litre.
1 pint = 4 gills = 0·568 ,,
1 qrt. = 2 pts. = 8 gills = 1·135 ,,
1 gall. = 4 qrts. = 8 pts. = 32 gills = 4·543 ,,
1 peck = 2 galls. = 8 qrts. = 16 pts. = 9·087 ,,
1 bush. = 4 pecks = 8 galls. = 32 qrts. = 36·348 ,,
1 quarter = 8 bush. = 32 pecks = 64 galls. = 2·908 hectolitres.

1 bushel= 1·283 cubic feet.

The gallon (dry or liquid)= 277·463 cubic inches.

6¼ gallons= 1 cubic foot (approx.).

A firkin is 9, a kilderkin 18, a barrel 36, a hogshead 54, a puncheon 72, a cask or butt 108, and a pipe 126 gallons.

Metric System.

With British Equivalents.

(Used in France, Austria, Belgium, Denmark, Egypt, Germany, Italy, Portugal, and Spain).

Weight.

Milligramme	=$\frac{1}{1000}$ gmme.	= 0·015 grs.	
Centigramme	=$\frac{1}{100}$,,	= 0·154 ,,	
Decigramme	=$\frac{1}{10}$,,	= 1·543 ,,	
Gramme	=1 ,,	= 15·432 ,,	
Decagramme	=10 ,,	= 0·353 oz.	avr.
Hectogramme	=100 ,,	= 3·527 ,,	,,
Kilogramme	=1000 ,,	= 2·205 lb.	,,
Myriagramme	=10 kilogrammes	= 22·046 ,,	,,
Quintal	=100 ,,	= 1·968 cwt.	,,
Millier, bar, or tonneau	=1000 ,,	= 0·984 tons	,,
1 kilogmme. per square centimètre		= 14·2 lbs. per square inch.	

Linear Measure.

Millimètre	=$\frac{1}{1000}$ mètre	= 0·039 in.
Centimètre	=$\frac{1}{100}$,,	= 0·394 ,,
Decimètre	=$\frac{1}{10}$,,	= 3·937 ,,
Mètre	=1 ,,	= 3·281 ft.
Decamètre	=10 ,,	= 10·936 yds.
Hectomètre	=100 ,,	= 109·362 ,,
Kilomètre	=1000 ,,	= 0·621 mile.
Myriamètre	=10 kilomètres	= 6·214 ,,

The old French toise=6·395ft.; the French nœud=British nautical mile.

Superficial Measure.

1 sq. millimètre	=$\frac{1}{1000000}$ sq. mètre	= 0·00155 sq. in.	
1 sq. centimètre	=$\frac{1}{10000}$,,	= 0·155 ,,	
1 sq. decimètre	=$\frac{1}{100}$,,	= 15·5 ,,	
1 milliare*	=$\frac{1}{10}$,,	= 1·076	sq. ft.
1 centiare*	=1 ,,	= 10·7641	,,
1 deciare*	=10 ,,	= 11·96	sq. yds.
1 are* or sq. decamètre	=100 ,,	= 119·601	,,
1 decare*	=1000 ,,	= 0·247	acres.
1 hectare* or sq. hectomètre	=10000 ,,	= 2·4711	,,

* Used for land measurement.

Cubic Measure.

1 cub. millimètre	$=\frac{1}{1000000000}$	cub. mètre	=	0·000061 cub. in.
1 cub. centimètre	$=\frac{1}{1000000}$	,,	=	0·061 ,,
1 millistere* or cub. decimètre	$=\frac{1}{1000}$	,,	=	61·025 ,,
1 centistere*	$=\frac{1}{100}$	,,	=	610·25 ,,
1 decistere*	$=\frac{1}{10}$	,,	=	3·532 cub. ft.
1 stere*	=1	,,	=	1·308 cub. yds.
1 decastere*	=10	,,	=	13·08 ,,
1 hectostere*	=100	,,	=	130·799 ,,
1 kilostere* or cub. decamètre	=1000	,,	=	1307·989 ,,

* Used for trade purposes.

Capacity.

1 millilitre	$=\frac{1}{1000}$ litre	=	0·061 cub. in.
1 centilitre	$=\frac{1}{100}$,,	=	0·61 ,,
1 decilitre	$=\frac{1}{10}$,,	=	0·705 gills.
1 litre	=1 ,,	=	0·881 qrts.
1 decalitre	=10 ,,	=	2·202 galls.
1 hectolitre	=100 ,,	=	22·0215 ,,
1 kilolitre	=1000 ,,	=	27·527 bush.
1 myriolitre	=10000 ,,	=	34·41 qrtrs.

1 millilitre=1 cubic centimètre; 1 litre=1 cubic decimètre; 1 kilolitre=1 cubic mètre.

INDIAN.

With British Equivalents.

Authorized.

In General Use in Northern India.

Weight.

1 tola	=	·41	ozs.
1 chittack	= 5 tolas	= 2·06	,,
1 seer	=16 chits	= 2·06	lbs.
1 maund	=40 seers	=82·2857	,,

Linear Measure.

1 jáo	=	·23	ins.
1 gaz	= 144 jáo	=	·92 yards.
1 kos	=4000 gaz	=2·08	miles.

(The trade maund varies in different districts).

Superficial Measure.

1 sq. gaz	=	·84	sq. yds.
1 baus	= 9 sq. gaz	=7·56	,,
1 bîga	=400 baus	= ·624	acres.
8 kanâls		=1	acre.

Capacity.

1 seer	=	·98	qrt.
1 páli	= 5 seers	=1·23	gal.
1 maund	=40 seers	=9·81	,,

Madras.

Weight.

1 pollam	= 3 tôla	= 1·23	ozs.
1 vis	=40 pollams	= 3·09	lbs.
1 maund	= 8 vis	=24·69	,,
1 candy	=20 maunds	= 4·41	cwt.

Linear Measure.

1 span		=8	inches.
1 cubit	=2¼ span	=1·5	feet.
1 kos	=8000 cubits	=2·27	miles.

Superficial Measure.

1 kôl ..... = 24 sq. ft.
1 gûli = 24 kôl ..... = 576 ,,
1 kâni = 100 gûli ..... = 1·32 acre.

Capacity.

1 olak ..... = 8 cub. in.
1 padi = 12½ olak ... = 100 ,,
1 mercal = 100 olak ..... = 2·88 gal.
1 para = 5 mercal ... = 14·4 ,,
1 gâs = 80 paras ... = 1152 ,,

Bombay.

Weight.

1 seer ..... = ·7 lbs.
1 maund = 40 seers ..... = 28 ,,
1 candy = 20 maunds ..... = 5 cwt.

Linear Measure.

1 tasû ..... = 1·125 in.
1 hâth = 16 tasû ..... = 1·5 ft.
1 gaz = 1½ hâth ..... = 2·25 ,,

Superficial Measure.

1 kati ..... = 10 sq. yds.
1 pand = 20 kati ..... = 200 ,,
1 bîga = 20 pand ..... = ·825 acre.

Capacity.

1 seer ..... = 49 cub. in.
1 paili = 4 seers ..... = ·71 gall.
1 para = 16 paili ..... = 11·34 ,,
1 candy = 8 para ..... = 90·74 ,,

Other Foreign Countries.

China.—Pecul = 133⅓ lbs.; yin = 117½ feet; tau = 1·13 gallons.

Egypt.—Rotl = ·99 lbs.; oke = 2·75 lbs.; gantar = ·884 cwt.; pic = 2·46 feet; gassaba = 11·65 feet; feddan = 1·038 acre; ardeb = 5·444 bushels.

Russia.—Pud = 36·11 lbs.; pound = 0·903 lbs; verst = ·663 miles; sagène = 7 feet; dessatine = 2·7 acres; sq. sagène = 49 sq. feet; vedro = 2·7 gallons; kruschki = 1·08 quart.

Sweden.—Skeppund = 3·35 cwt.; skalpund = 0·94 lb.; mile = 6·6 miles; fathom = 5·84 feet; foot = 0·97 foot; tunnland = 1·22 acres; sq. foot = 0·95 sq. foot; cub. foot = 0·92 cub. foot; am = 34·58 gallons; kann = 0·58 gallon.

Turkey.—Rotl = 1·27 lb.; pik = 26·625 inches; almud = 1·1455 gallons; killow = ·97 bushel.

FORMULÆ AND DATA.

Timber Measuring.

G = ¼ girth of the tree at the middle in feet.
g = ¼ ,, ,, one end ,,
g' = ¼ ,, ,, other end ,,
L = length of log in feet.
C = cubic contents of log in feet.

$$C = L\left(\frac{G + g + g'}{3}\right)^2.$$

Allow for bark by deducting from each ¼ girth.

Cask Measuring.

C = circumference of the cask in feet halfway between the bung and the head. L = length in feet measured along a stave exclusive of its projections, and W = weight

of empty cask in lbs.; then actual buoyancy in lbs. = 5 $C^2L - W$.

If the capacity of a cask in gallons is known, buoyancy in lbs. = gallons × 10 − weight of cask.

Dimensions, Weight, and Buoyancy of Different Casks.

Name.	Capacity in Gallons.	Dimensions.			Weight when empty.	Weight of Water displaced.	Actual Buoyancy.
		Extreme Bung Diameter.	Extreme Length, Measured along Stave.	Circumference half-way between bung and head.			
		In.	Ft.	Ft.	lbs.	lbs.	lbs.
Leager	170	38·5	4·52	9·33	252	1988	1736
Butt	108	33·3	3·97	8·09	174	1299	1125
Puncheon	72	30·7	3·20	7·57	140	917	777
Hogshead	54	28·6	2·76	7·05	119	686	567
Barrel	36	25·3	2·42	6·23	88	470	382
Half hogshead ..	26	22·7	2·12	5·61	65	334	269
Kilderkin	18	20·3	1·81	5·02	49	234	185
Small cask ..	14	18·3	1·76	4·49	32	178	146
Small cask ..	6	13·8	1·37	3·40	20	80	60

Ropes and Chains.

w = weight of rope in lbs. per fathom.

c = actual circumference of rope in inches.

$w = c^2$ for wire rope.

$= \frac{c^2}{4}$,, tarred rope.

$= \frac{c^2}{5}$,, hemp ,,

$= \frac{c^2}{5 \cdot 5}$,, manilla ,,

$= \frac{c^2}{10}$,, coir ,,

Safe load for ordinary work= c^2 cwts., but under favourable conditions this may be increased to a *maximum* of $2c^2$.

White rope is about $\frac{1}{7}$ lighter, rather stronger, and 40 per cent. less stiff than tarred rope. Coir rope is about $\frac{1}{4}$ the strength of hempen rope, and only $\frac{2}{3}$ its weight. Manilla about $\frac{1}{3}$ weaker and $\frac{1}{6}$ lighter than hemp.

Cable-laid wire ropes have less strength (about $\frac{2}{3}$) than hawser-laid ropes of the same circumference. They stretch much more, but are more supple. Steel-wire rope is at least twice as strong and about the same weight as wire rope. Weight of wire rope= c^2 lbs. per fathom, and breaking strain= c^2 tons for iron and $2c^2$ tons for steel wire.

The strength of chain varies as the square of the diameter of the iron in the link. The relative strength of chain and rope may be taken as 7 : 1, using the diameter of link and circumference of rope. Thus $\frac{1}{2}$″ chain may replace $3\frac{1}{2}$″ rope. In order to obtain the weight per fathom of crane chain numerator reduce the diameter of iron to fraction with 8 denominator, and the square of the numerator of this fraction gives the weight in pounds. Thus a $\frac{5}{8}$″ chain weighs 25lbs. Studded chain is $1\frac{1}{2}$ times as strong as crane chain. Chains are heavier than ropes for a given strength in the proportion of 6 to 1; they are more costly in proportion of 3 to 1, but the balance in endurance is much in favour of chains, as hempen ropes deteriorate rapidly after a few months' wear, sometimes as much as 50 per cent.

Rule for safe load on chains :—

D = diameter in eights of an inch.

S = safe load in tons.

$$D = \sqrt{8\mathbf{S}}.$$

$$\mathbf{S} = \frac{D^2}{9}.$$

Weights and Strength of Ropes and Chains.

Hemp Rope.		Wire Rope.				Chain, round link, length of link not > 5 diam. of iron.		Working Strain in cwt.
		Iron.		Steel.				
Circum.	Weight per Fath.	Circum.	Weight per Fath.	Circum.	Weight per Fath.	Diam. of Iron in Link.	Weight per Fath.	
In.	lbs.	In.	lbs.	In.	lbs.	In.	lbs.	Cwts.
1	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$					1
				$\frac{3}{8}$	$\frac{1}{7}$			$1\frac{1}{8}$
				$1\frac{7}{16}$	$\frac{5}{14}$			$1\frac{1}{2}$
				$\frac{1}{2}$	$\frac{1}{4}$			2
$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$					$2\frac{1}{4}$
2	1	1	1					4
				$\frac{3}{4}$	$\frac{1}{2}$			$4\frac{1}{2}$
						$\frac{3}{16}$	2	5
$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$					$6\frac{1}{4}$
				1	1			8
3	2	$1\frac{1}{2}$	$2\frac{1}{4}$			$\frac{1}{4}$	$4\frac{1}{2}$	9
$3\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{3}{4}$	3	$1\frac{1}{4}$	$1\frac{1}{2}$			$12\frac{1}{2}$
						$\frac{5}{16}$	$6\frac{1}{4}$	14
4	$3\frac{1}{2}$	2	4					16
				$1\frac{1}{2}$	$1\frac{3}{4}$			18
$4\frac{1}{2}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$4\frac{1}{2}$			$\frac{3}{8}$	9	20
5	$5\frac{1}{4}$	$2\frac{1}{2}$	$5\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$			25
						$\frac{7}{16}$	12	27
$5\frac{1}{2}$	$6\frac{1}{2}$	$2\frac{3}{4}$	$6\frac{1}{2}$					30
				2	$2\frac{3}{4}$			32
6	$7\frac{1}{2}$	3	$7\frac{1}{2}$			$\frac{1}{2}$	16	36
				$2\frac{1}{4}$	$3\frac{1}{2}$			40
$6\frac{1}{2}$	9							$42\frac{1}{2}$
						$\frac{9}{16}$	20	45

These strains are for ropes exposed to the weather under continuous strains.

Factors of safety :—3 for hemp rope, 5 for wire rope, 2 for chain.

Weights and Strength of Ropes and Chains.—Cont.

Hemp Rope.		Wire Rope.				Chain, round link, length of link not > 5 diam. of iron.		Working Strain in cwt.
		Iron.		Steel.				
Circum.	Weight per Fath.	Circum.	Weight per Fath.	Circum.	Weight per Fath.	Diam. of Iron in Link.	Weight per Fath.	
In.	lbs.	In.	lbs.	In.	lbs.	In.	lbs.	Cwts.
7	$10\frac{1}{4}$	$3\frac{1}{2}$	$10\frac{3}{4}$	$2\frac{1}{2}$	$4\frac{1}{2}$	—	—	50
$7\frac{1}{2}$	$11\frac{3}{4}$	—	—	—	—	$\frac{5}{8}$	25	56
—	—	—	—	$2\frac{3}{4}$	$5\frac{1}{2}$	—	—	60
8	$13\frac{1}{2}$	4	$13\frac{3}{4}$	—	—	$\frac{11}{16}$	29	64
$8\frac{1}{2}$	15	—	—	3	7	—	—	72
9	17	$4\frac{1}{2}$	$17\frac{3}{4}$	—	—	$\frac{3}{4}$	36	81
$9\frac{1}{2}$	19	—	—	—	—	—	—	90
—	—	—	—	—	—	$\frac{13}{16}$	41	93
10	21	5	$21\frac{1}{2}$	$3\frac{1}{2}$	9	—	—	100
$10\frac{1}{2}$	23	—	—	—	—	$\frac{7}{8}$	49	110
11	$25\frac{1}{4}$	$5\frac{1}{2}$	$26\frac{1}{2}$	—	—	—	—	120
—	—	—	—	4	12	$\frac{15}{16}$	54	126
$11\frac{1}{2}$	$27\frac{1}{2}$	—	—	—	—	—	—	132
12	30	6	$31\frac{1}{2}$	—	—	1	62	144
—	—	—	—	$4\frac{1}{2}$	15	—	—	162
—	—	$6\frac{1}{2}$	$40\frac{1}{2}$	—	—	—	—	169
—	—	—	—	—	—	$1\frac{1}{8}$	75	180
—	—	7	$42\frac{1}{2}$	5	23	—	—	198
—	—	—	—	—	—	$1\frac{1}{4}$	95	222
—	—	—	—	$5\frac{1}{2}$	28	—	—	242
—	—	—	—	—	—	$1\frac{3}{8}$	112	269
—	—	—	—	6	31	—	—	288
—	—	—	—	—	—	$1\frac{1}{2}$	135	320

These strains are for ropes exposed to the weather under continuous strains.

Factors of safety:—3 for hemp rope, 5 for wire rope, 2 for chain.

Weights of Materials in lbs. per Cubic Foot.

Stones, Earth, etc.

Brickwork, common stock	115	Freestone, hewn	140
Brickwork, red-facing	130	Granite	165
Brickwork, laid in cement	110	Gravel and sand mixed	110
Chalk, solid	112	Limestone	160
Clay, potter's	120	Lime, ordinary quick	53
Coal	80	Masonry	140 to 160
Coke	47	Mud	102
Concrete, Portland	120	Sand	120
Earth, semi-fluid	100	Slate	180
,, loamy	80	Trap and whinstone	172

Woods (Seasoned).

These weights are for seasoned woods which have lost one-third or one-fourth of their weight by drying in the air for some 10 or 12 months. *For green wood 30 per cent. should be added to the weights here given.*

Acacia	50	Ebony	74
Alder	32	Elder	42
Apple	49	Elm, English	37
Ash	45	Fir, Dantzic	40
Bamboo	25	,, Riga	33
Bay	50	,, Memel	36
Beech	43	Greenheart	70
Birch	44	Hazel	40
Blue gum	63	Hornbeam	47
Box	61	Larch	35
Brazil wood, red	64	Laburnum	57
Cedar, Cuban	29	Lancewood	59
,, American	32	Lignum vitæ	83
,, Lebanon	30	Mahogany	41
Chir (primo longifolia)	32	Maple	32
Chestnut	41	Oak, English	57
Cork	15	,, American	53
Deodar	40	Pine, pitch	43
Deal	43	,, red	39

Pine, yellow	33	Teak	51
Poplar	27	Walnut	38
Sâl	60	Willow	25

Metals.

Brass (cast)	524	Iron (cast)	450
Brass wire	534	Lead ,,	712
Bronze	513	Steel	493
Copper (coin)	550	Tin (cast)	456
Gunmetal	549	Zinc	449
Iron, wrought	484		

The following substances weigh 1 ton each :—21 cub. ft. of sand ; 18 of earth ; 17 of clay ; 64 of fir ; 39 of oak ; 60 of elm ; 17 of Bath stone ; 13 of marble.

The average weight of a bushel of oats is 40, and of wheat 60lbs.

One cubic foot water weighs at 40 degrees Fahr. 62·425 lbs. when fresh, or 64lbs. salt ; one gallon weighs 10lbs.

Weight of roofing may be taken as—Double-tiled, 30lbs. ; single-tiled, 15lbs. ; slate, 9lbs. ; thatch (9″ thick), 10lbs. ; corrugated iron 18 B.W.G., 5lbs. ; and flat earth (1′ thick), 100lbs. per square foot.

The maximum weight for floors should be in ordinary dwellings 1¼cwt. per square foot ; but in magazines or store-houses this may have to be increased, according to the weight of stores for which accommodation is required. For bridges 100lbs. per square foot is sufficient for a disorganized mass of men, but the weight of the heaviest ammunition wagon or other vehicle used with the column that has to cross the bridge will be the guide for calculation of the strength of the component parts of the bridge.

Weights of pack animals loaded are as follows :—

	Space occupied.	Total Weight.	Max. Weight on one foot.
Elephants	(11×9) 99 sq. ft.	72cwt.	44cwt.
Camels	(10×7) 70 ,,	15 ,,	10 ,,
Pack bullocks	(5×2¾) 13½ ,,	5½ ,,	3½ ,,
Cattle (unloaded)	9 ,,	4 ,,	—

Weights of guns, limbers, etc., will be found on pages 26 to 30.

Pipes.

D = outside diameter of pipe in inches.
d = inside diameter.
w = weight of lineal foot of pipe in lbs.
$w = K (D^2 - d^2)$. K = 2·46 for cast iron = 2·64 for wrought iron; 2·82 for brass; 3·03 for copper; and 3·86 for lead.

Average Safe Strains for Materials.

	Tensile.	Crushing.*
	Tons.	Tons.
Brass .. .. .. sq. in.	2	—
Copper	2·1	—
Gunmetal	4	—
Iron, Wrought	5	4
,, Cast	2	12
Steel	7	10
	lbs.	lbs.
Ash	2,400	1,750
Beech	2,200	1,500
Chir	700	700
Deodar	700	700
Elm	2,600	2,000
Fir	2,000	1,300
Oak	3,800	2,000
Pine	2,400	1,100
Sâl	1,200	1,200
Teak	1,600	2,400

* For columns whose length is less than 10 times smallest diameter; for longer columns use half these amounts.

Safe load on foundations—Loamy soil, 0·8 ton; stiff clay, 1 to 1½ ton; rocky soil, 1½ to 3½ tons per square foot.

Strength of Beams.

The beams most usually met with in field engineering are of two classes, viz. :—(1), supported at both ends and uniformly loaded ; or (2), supported at both ends and having to bear a load in the centre. Cantilevers may, however, also be sometimes required.

The timber which the military engineer may have to work with may be of a tree which is unknown to him, and which has not been the subject of previous scientific experiment. Hence a general formula is desirable which will give *safe results for any class of timber.*

The following general formulæ for a beam supported at both ends and loaded with a *uniform dead load* are applicable to any class of timber, provided it be sound :—

N.B.—A load at the centre is equivalent to twice the same load uniformly distributed. A live load is equivalent to twice the same amount of dead load. A cantilever requires four times the strength of a supported beam of same length and with similar load.

W = total safe load in lbs.
w = safe load in lbs. per square foot.
S = distance apart of beams from centre to centre, in feet.
L = unsupported length of beam in feet.
b = breadth of beam in inches.
d = depth of beam in inches.
D = diameter of round beam in inches.

(1). For rectangular beam—

$$bd^2 = \frac{L^2Sw}{200} \text{ or } bd^2 = \frac{WL}{200}.$$

(2). For round beams—

$$D^3 = \frac{L^2Sw}{120} \text{ or } D^3 = \frac{WL}{120}.$$

The above formulæ give a factor of safety of 3 for larch ; 4 for fir ; and 6 or 7 for hard woods such as ash, oak, teak, etc.

The following is another formula for rectangular beams supported at both ends and loaded with a total uniformly distributed *live* load in cwts.= **W** :—

$$bd^2 = \mathbf{W}L.$$

The strength of round poles is $\frac{6}{10}$ that of a square beam whose side= diameter of pole.

This formula gives practically the same result as the former ones, the factors of safety being about $\frac{1}{3}$ less.

Stiffness.

When the beam or pole is loaded with the safe load given above, the deflection will be about $\frac{1}{60}\frac{L^2}{d}$ for oak, fir, and mahogany ; for teak, about half that for fir.

As a rule, a beam, if strong enough, is for all practical purposes stiff enough.

Scantlings of Timber Beams, Uniformly Loaded and Supported.

b= breadth of beam in inches.
d= depth of beam in inches.
w= weight on beam in lbs. per foot super.
L= length of beam in feet.
S= distance apart in feet of two adjacent beams.
r= modulus of rupture in lbs. per square inch.
E= modulus of elasticity in lbs. per square inch.

For strength—

$$bd^2 = \frac{9\,L^2\,Sw}{r}.$$

For stiffness—

$$bd^3 = \frac{2160\,L^3\,Sw}{E}.$$

Values of "r" (factor of safety = 4) and "E" in above Formulæ.

Timber.	r.	E.
EUROPE—		
Ash	3,000	320,000
Beech	2,250	270,000
Elm	1,500	140,000
Spruce fir	2,475	288,000
Scotch fir, red fir, and northern pine	1,260	288,000
Larch	1,250	180,000
Oak	2,500	240,000
NORTH AMERICA—		
Oak	1,250	300,000
White pine	840	320,000
Red pine	1,775	292,000
Yellow pine	985	320,000
Spruce	740	320,000
INDIA—		
Babul	3,940	362,000
Bamboo	3,085	240,000
Deodar	2,700	300,000
Chir	2,700	340,000
Sâl	4,950	370,000
Teak	4,230	344,000
AUSTRALIA—		
Spotted gum	4,000	490,000
NEW ZEALAND—		
Kauri	2,000	576,000

Values of "bd^3," "b" varying from 1 to 6, "d" varying from 1 to 12.

Depth.	Breadth.																		
	1	1½	1¾	1¾	2	2½	2½	2¾	3	3½	3½	3¾	4	4½	4½	4¾	5	5¼	5½	5¾	6
1	1·0	1·2	1·5	1·7	2·0	2·2	2·5	2·7	3·0	3·2	3·5	3·7	4·0	4·2	4·5	4·7	5·0	5·2	5·5	5·7	6·0
1½	2·0	2·4	2·9	3·4	3·9	4·4	4·9	5·4	5·9	6·3	6·8	7·3	7·8	8·3	8·8	9·3	9·8	10·3	10·7	11·2	11·7
1½	3·4	4·2	5·1	5·9	6·7	7·6	8·4	9·3	10·1	11·0	11·8	12·7	13·5	14·3	15·2	16·0	16·9	17·7	18·6	19·4	20·2
1¾	5·4	6·7	8·0	9·4	10·7	12·1	13·4	14·7	16·1	17·4	18·8	20·1	21·4	22·8	24·1	25·5	26·8	28·1	29·5	30·8	32·2
2	8·0	10·0	12·0	14·0	16·0	18·0	20·0	22·0	24·0	26·0	28·0	30·0	32·0	34·0	36·0	38·0	40·0	42·0	44·0	46·0	48·0
2½	11·4	14·2	17·1	19·9	22·8	25·6	28·5	31·3	34·2	37·0	39·9	42·7	45·6	49·4	51·3	54·1	57·0	59·8	62·6	65·5	68·3
2½	15·6	19·5	23·4	27·3	31·2	35·2	39·1	43·0	46·9	50·8	54·7	58·6	62·5	66·4	70·3	74·2	78·1	82·0	85·9	89·8	93·7
2¾	20·8	26·0	31·2	36·4	41·6	46·8	52·0	57·2	62·4	67·6	72·8	78·0	83·2	88·4	93·6	98·8	104	109	114	120	125
3	27·0	33·7	40·5	47·2	54·0	60·7	67·5	74·2	81·0	87·7	94·5	101	108	115	121	128	135	142	148	155	162
3½	34·3	42·9	51·5	60·1	68·7	77·2	85·8	94·4	103	112	120	129	137	146	154	163	172	180	189	197	206
3½	42·9	53·6	64·3	75·0	85·8	96 5	107	118	129	139	150	161	171	182	193	204	214	225	236	247	257
3¾	52·7	65·9	79·1	92 3	103	119	132	145	158	171	185	198	211	224	237	250	264	277	290	303	316
4	64·0	80·0	96·0	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
4½	76·8	96·0	115	134	154	173	192	211	230	249	269	288	307	326	345	365	384	403	422	441	461
4½	91·1	114	137	159	182	205	228	251	273	296	319	342	364	387	410	433	456	478	501	524	547
4¾	107	134	161	188	214	241	268	295	322	348	375	402	429	445	482	509	536	563	589	616	643
5	125	156	187	219	250	281	312	344	375	406	437	469	500	531	562	594	625	656	687	719	750
5¼	145	181	217	253	289	326	362	398	434	470	506	543	579	615	651	687	724	760	796	832	868
5½	166	208	250	29:	333	374	416	458	499	541	582	624	665	707	749	790	832	873	915	957	998
5¾	190	238	285	333	380	428	475	523	570	618	665	713	760	808	855	903	951	998	1046	1093	1141

Values of "bd^3," "b" varying from 1 to 6, "d" varying from 1 to 12.—Cont.

Depth.	Breadth.																			
	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
6	216	270	324	378	432	486	540	594	648	702	756	810	864	918	972	1026	1080	1134	1188	1242	1296
6¼	244	305	366	427	488	549	610	671	732	793	855	916	977	1038	1099	1160	1221	1282	1343	1404	1465
6½	275	343	412	481	549	618	687	755	824	893	961	1030	1098	1167	1236	1304	1373	1442	1510	1579	1648
6¾	308	384	461	538	615	692	769	846	923	1000	1076	1153	1230	1307	1384	1461	1538	1615	1692	1768	1845
7	343	429	514	600	686	772	857	943	1029	1115	1200	1286	1372	1458	1543	1629	1715	1801	1886	1972	2058
7¼	381	476	572	667	762	857	953	1048	1143	1238	1334	1429	1524	1620	1715	1810	1905	2001	2096	2191	2286
7½	422	527	633	738	844	949	1055	1160	1266	1371	1477	1582	1687	1793	1898	2004	2109	2215	2320	2426	2531
7¾	465	582	698	815	931	1047	1164	1280	1396	1513	1629	1746	1862	1978	2095	2211	2327	2444	2560	2677	2793
8	512	640	768	896	1024	1152	1280	1408	1536	1664	1792	1920	2048	2176	2304	2432	2560	2688	2816	2944	3072
8¼	562	702	842	983	1123	1263	1404	1544	1685	1825	1965	2106	2246	2386	2527	2667	2808	2948	3088	3229	3369
8½	614	768	921	1075	1228	1382	1535	1689	1842	1996	2149	2303	2456	2610	2763	2917	3071	3224	3378	3531	3685
8¾	670	837	1005	1172	1340	1507	1675	1842	2010	2177	2345	2512	2680	2847	3015	3182	3350	3517	3685	3852	4020
9	729	911	1093	1276	1458	1640	1822	2005	2187	2369	2551	2734	2916	3098	3280	3463	3645	3827	4009	4192	4374
9¼	791	989	1187	1385	1583	1781	1979	2176	2374	2572	2770	2968	3166	3364	3562	3759	3957	4155	4353	4551	4749
9½	857	1072	1286	1500	1715	1929	2143	2358	2572	2786	3001	3215	3429	3644	3858	4073	4289	4501	4716	4930	5144
9¾	927	1159	1390	1622	1854	2085	2317	2549	2781	3012	3244	3476	3707	3939	4171	4403	4634	4866	5098	5329	5561
10	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500	5750	6000
11	1331	1664	1997	2329	2662	2995	3328	3660	3993	4326	4659	4991	5324	5657	5990	6322	6655	6988	7321	7653	7986
12	1728	2160	2592	3024	3456	3888	4320	4752	5184	5616	6048	6480	6912	7344	7776	8208	8640	9072	9504	9936	10368

Values of "bd^2," "b" varying from 1 to 6, "d" varying from 1 to 12.

Depth.	Breadth.																				
	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
1	1·0	1·2	1·5	1·7	2·0	2·2	2·5	2·7	3·0	3·2	3·5	3·7	4·0	4·2	4·5	4·7	5·0	5·2	5·5	5·7	6·0
1¼	1·6	2·0	2·3	2·7	3·1	3·5	3·9	4·3	4·7	5·1	5·5	5·9	6·2	6·6	7·0	7·4	7·8	8·2	8·6	9·0	9·4
1½	2·2	2·8	3·4	3·9	4·5	5·1	5·6	6·2	6·7	7·3	7·9	8·4	9·0	9·6	10·1	10·7	11·2	11·8	12·4	12·9	13·5
1¾	3·1	3·8	4·6	5·4	6·1	6·9	7·7	8·4	9·2	10·0	10·7	11·5	12·3	13·0	13·8	14·6	15·3	16·1	16·8	17·6	18·4
2	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0	16·0	17·0	18·0	19·0	20·0	21·0	22·0	23·0	24·0
2¼	5·1	6·3	7·6	8·9	10·1	11·4	12·7	13·9	15·2	16·2	17·7	19·0	20·2	21·5	22·8	24·0	25·3	26·6	27·8	29·1	30·4
2½	6·2	7·8	9·4	10·9	12·5	14·1	15·6	17·2	18·7	20·3	21·9	23·4	25·0	26·6	28·1	29·7	31·2	32·8	34·4	35·9	37·5
2¾	7·6	9·5	11·3	13·2	15·1	17·0	18·9	20·8	22·7	24·6	26·5	28·4	30·2	32·1	34·0	35·9	37·8	39·7	41·6	43·5	45·4
3	9·0	11·2	13·5	15·7	18·0	20·2	22·5	24·7	27·0	29·2	31·5	33·7	36·0	38·2	40·5	42·7	45·0	47·2	49·5	51·7	54·0
3¼	10·6	13·2	15·8	18·5	21·1	23·8	26·4	29·0	31·7	34·3	37·0	39·6	42·2	44·9	47·5	50·2	52·8	55·5	58·1	60·7	63·4
3½	12·2	15·3	18·4	21·4	24·5	27·6	30·6	33·7	36·7	39·8	42·9	45·9	49·0	52·1	55·1	58·2	61·2	64·3	67·4	70·4	73·5
3¾	14·1	17·6	21·1	24·6	28·1	31·6	35·2	38·7	42·2	45·7	49·2	52·7	56·2	59·8	63·3	66·8	70·3	73·8	77·3	80·9	84·4
4	16·0	20·0	24·0	28·0	32·0	36·0	40·0	44·0	48·0	52·0	56·0	60·0	64·0	68·0	72·0	76·0	80·0	84·0	88·0	92·0	96·0
4¼	18·1	22·6	27·1	31·6	36·1	40·6	45·2	49·7	54·2	58·7	63·2	67·6	72·2	76·8	81·3	85·8	90·3	94·8	99·3	104	108
4½	20·2	25·3	30·4	35·4	40·5	45·6	50·6	55·7	60·7	65·8	70·9	75·9	81·0	86·1	91·1	96·2	101	106	111	116	121
4¾	22·6	28·2	33·8	39·5	45·1	50·8	56·4	62·0	67·7	73·3	79·0	84·6	90·2	95·9	102	107	113	118	124	130	135
5	25·0	31·2	37·5	43·7	50·0	56·2	62·5	68·7	75·0	81·2	87·5	93·7	100	106	112	119	125	131	137	144	150
5¼	27·6	34·5	41·3	48·2	55·1	62·0	68·9	75·8	82·7	89·6	96·5	103	110	117	124	131	138	145	152	158	165
5½	30·2	37·8	45·4	52·9	60·5	68·1	75·6	83·2	90·7	98·3	106	113	121	129	136	144	151	159	166	174	181
5¾	33·1	41·3	49·6	57·9	66·1	74·4	82·7	90·9	99·2	107	116	124	132	141	149	157	165	174	182	190	198

Values of "bd²," "b" varying from 1 to 6, "d" varying from 1 to 12:—Cont.

Depth.	Breadth.																			
	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
6	36·0	45·0	54·0	63·0	72·0	81·0	90·0	99·0	108	117	126	135	144	153	162	171	180	189	198	207	216
6¼	39·1	48·8	58·6	68·4	78·1	87·9	97·7	107	117	127	137	146	156	166	176	186	195	205	215	225	234
6½	42·2	52·8	63·4	73·9	84·5	95·1	106	116	127	137	148	158	169	180	190	201	211	222	232	243	253
6¾	45·6	57·0	68·3	79·7	91·1	103	114	125	137	148	159	171	182	194	205	216	228	239	251	262	273
7	49·0	61·2	73·5	85·7	98·0	110	122	135	147	159	171	184	196	208	220	233	245	257	269	282	294
7¼	52·6	65·7	78·9	92·0	105	118	131	145	158	171	184	197	210	223	237	250	263	276	289	302	315
7½	56·2	70·3	84·4	98·4	112	127	141	155	169	183	197	211	225	239	253	267	281	295	309	323	337
7¾	60·1	75·1	90·1	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
8	64·0	80·0	96·0	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
8¼	68·1	85·1	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408
8½	72·2	90·3	108	126	144	163	181	199	217	235	253	271	289	307	325	343	361	379	397	415	433
8¾	76·6	95·7	115	134	153	172	191	211	230	249	268	287	306	325	345	364	383	402	421	449	459
9	81·0	101	121	142	162	182	202	223	243	263	283	304	324	344	364	385	405	425	445	466	486
9¼	85·6	107	128	150	171	193	214	235	257	278	299	321	342	364	385	406	428	449	470	492	513
9½	90·2	113	135	158	180	203	226	248	271	293	316	338	361	384	406	429	451	474	496	519	541
9¾	95·1	119	143	166	190	214	238	261	285	309	333	356	380	404	428	452	475	499	523	547	570
10	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600
11	121	151	181	212	242	272	302	333	363	393	423	454	484	514	544	575	605	635	665	696	726
12	144	180	216	252	288	324	360	396	432	468	504	540	576	612	648	684	720	756	792	828	864

Strength of Rails.

Let w = weight of rail in lbs. per yard run.
S = working load in tons it will bear.
L = length between supports in feet.

$$S = \cdot 02 \times \frac{w^{\frac{3}{2}}}{L} \text{ for load in centre}$$

Then $$= \cdot 04 \times \frac{w^{\frac{3}{2}}}{L} \text{ for uniform load.}$$

For ordinary rails used on English railways $5\frac{1}{2}''$ deep $S = \frac{0{\cdot}73\ w}{L}$ for a uniform load. Or if d = depth in inches, $S = \frac{1{\cdot}6\ wd}{12\ L}$.

The above are safe approximate rules for both double-headed and flat-bottomed rails of steel, as ordinarily found on modern railways.

Strength of Rails used as Girders.

Dead load distributed .. .. .. $\frac{WL}{8} = \frac{rI}{y}$

Do. do. concentrated in centre .. .. $\frac{WL}{4} = \frac{rI}{y}$

Where W = load in tons, L = length in inches, r = modulus of rupture (safe), y = distance in inches from neutral layer to extreme fibre, and I = moment of inertia.

Values of I, *y, and r in some Steel Rails.*

	I	y	r	$\frac{rI}{y}$
100lb.	45·38	3·	6·5	98·3
84lb.	30·37	2·84	,,	69·5
80lb.	24·79	2·54	,,	63·4
75lb.	22·1	2·45	,,	58·6
70lb.	18·0	2·45	,,	47·9
68lb.	20·2	2·5	,,	52·6
64lb.	19·6	2·5	,,	50·9

Earthwork.

A cubic yard an hour is the usual task from unskilled diggers in easy soil, or 100 cubic feet in four hours, throwing a maximum horizontal distance of 12 feet, and a vertical lift not exceeding 4 feet.

The above is, however, for *easy* soil, and unless a soldier has had considerably more practice in digging than usually falls to his lot, it will be found that if in ordinary soil he does 60 cubic feet at first in four hours, it is as much as one can generally get on an average. After a little practice, he ought to be able to do 100 cubic feet in four hours. Sappers can do a yard and a-half in an hour. The result of trial between sappers and infantry was that the R.E. could do 30 per cent. more work than infantry in a given time—four hours.

In very stiff soil, gravel, or clay half-tasks should be estimated for.

In estimates for working parties in ordinary unknown soil 120 cubic feet in six hours, or 20 cubic feet an hour, per man, is fair. Much depends on the health of the working party, the nature of their tools, and their discipline. With the light infantry tools only half the above tasks can be expected.

Each battalion infantry carries in the field 128 intrenching and 26 heavy picks and 256 intrenching and 25 universal shovels, also 12 crowbars. A cavalry regiment carries 26 picks (of which 20 are light), 40 shovels (light), 6 spades, 7 crowbars. A battery of artillery has 12 picks and 24 spades.

The tools of the R.E. are too numerous and miscellaneous to be mentioned here. Lists will accompany each unit on service. They vary according to the nature of the country.

Brick Arch Bridges.

For brick arches to carry the ordinary loads (traction engines or heavy artillery) a rough rule for the thickness of the arch ring is ½ brick to every 5′ of clear span.

Short spans require some addition to this, *e.g.*, a 10′ arch is best 1½ bricks and a 50′ arch may be less than 5 bricks (=3′ 9″), but the rule is generally safe.

A more accurate rule is

$$d = \frac{\sqrt{r + \frac{1}{2}s}}{4} + \cdot 2$$

where r = radius of the arch in feet.

s = span in feet.

d = depth of ring in feet.

Add about $\frac{1}{3}d$ for brickwork.

Penetration of Rifle Bullets.

Material.	Maximum Observed Penetration at 40 yards.	Remarks.
Clay	5′	According to character of clay.
Earth free from stones (unrammed).	3′	Ramming earth reduces its resisting power. The resistance of a sod revetment is approximately the same as that of loose earth.
Sand	2′ 6″	Between boards 18″.
Brickwork, near joint.	4½″	
Soft wood, such as fir.	4′	26″ proof at 500 yards.
Hard wood, such as oak.	27″	17″ proof at 500 yards.
Wrought iron or mild steel plate.	1⅝″	This thickness was only dented at 500 yards.
Hardened steel plate.	¼″	A thickness of 1½″ was proof at 600 yards.
Coarse shingle (1½″).	6″	
Fine shingle (½″) in boxes.	8″	
Ordinary macadam from road.	6″	
Coal	2′ 6″	
Chalk	1′	When freshly excavated.

Aimed fire, 24 shots per minute maximum.

The penetration given above are for single shots at 40 yards range.

With *dry* timber, a greater thickness should be allowed.

Miscellaneous.

The Maxim can fire 10 bullets per second.

The 1·457″ Vickers-Maxim fires a 1lb. steel common shell, with a bursting charge of 270 grains of black powder. Penetration into wrought iron, 2·25″ at the muzzle. Slope of descent, 6° 6′ at 2,000 yards, and 11° 33′ at 3,000 yards. Muzzle velocity, 1,800 f.s.; velocity at 3,000 yards, 561 f.s.

The 3-pounder quick-firing gun fires from 10 to 15 aimed rounds per minute. Projectiles :—Common shell of cast iron and steel.

The penetration of steel shell at 500 yards is 2½″ in steel plate, or at 1,000 yards 2½″ in wrought iron. Cast-iron shell at 3,000 yards, 20″ oak, being accurate up to 2,500 yards. Can be served by two men.

Penetration of Projectiles.

Against modern B.L. field guns, at medium ranges, the following thickness of cover will probably suffice, except against common shell :—

Sand	2 yards.
Ordinary soil	2½ ,,
Clay	3 ,,

In a clay soil masses are detached by the burst of shells ; in light soils the effect is trifling.

Bridge Loads due to Animals.

Purpose.	Description.	Weight in lbs.					Area occupied on bridge.		Weight per Square Foot.	Distances.		
		Of Animal.	Of Load.	Total.	On Hind Legs.	On Fore Legs.*	Dimensions.	Square Feet.		From Front Axle to Hind Legs.	From Hind Legs to Fore Legs.	From Front Legs to Hind Legs of Animal in Front.
										ft. in.	ft. in.	ft. in.
Draught.	Light horses ..	1,200	...	...	480	720	...	...	...	4 6	4 0	4 0
	Artillery horses...	1,400	...	...	560	840	...	...	...	4 6	4 0	4 0
	Farm horses ...	1,700	...	...	680	1,020	...	...	...	4 6	4 0	4 0
	Shire horses ...	2,000	...	...	800	1,200	...	...	...	4 6	4 0	4 0
	15-hand mules ...	1,000	...	...	400	600	...	...	...	4 6	4 0	4 0
	Oxen	...	...	...	...	...	...	...	...	...	...	...
	Elephants ...	7,500	...	...	3,000	4,500	11′×5′	55	82	5 6	6 6	10 6
Pack.	Horses	1,400	200	1,600	640	960	...	...	...	...	...	...
	Mules	1,000	160	1,160	460	700	...	...	...	...	...	...
	Indian bullocks...	450	150	600	200	400	5′×2′9″	13·5	44	...	3 6	...
	Elephants ...	7,000	1,500	8,500	3,500	5,000	11′×9′	100	85	...	6 6	...
	Camels	1,200	400	1,600	600	1,000	10′×7′	70	23	...	4 6	...
Commissariat.	Cattle	1,000	...	...	...	...	...	10	100	...	...	...

* This may be taken as the greatest weight that can be brought on to any one foot.

Bridge Loads, etc., due to Guns and Vehicles.

Description of Vehicle.	Weight in lbs. With Full Load, including Men. Fore or Limber Wheels.	Weight in lbs. With Full Load, including Men. Hind or Gun Wheels.	Distances. Front Axle to Hind Legs of Horse.	Distances. Axle to Axle.	Distances. Hind Axle to Fore Legs of Horses following.	Wheel Track Out to Out.	Width of Tyre.	Greatest Projection beyond Track.
Vehicles Common to all Arms.			ft. in.	ft. in.	ft. in.	ft. in.	in.	in.
Wagon, General Service, Mark IV. ...	3,250	2,360	4 6	6 1	6 0	5 3	2½	5
,, ,, Mark VIII...	3,050	2,400	4 6	7 6	6 0	5 3	2½	5
,, ,, Mark X. ...	3,050	2,300	4 6	7 1	6 0	5 3	2½	6
Artillery Vehicles.								
Gun and carriage, field, Q.F. 13-pr., Mark I., with limber.	1,920	2,570	4 6	9 11½	6 6	5 3	3	6
Wagon, ammunition, Q.F. 13-pr., Marks I. and II., with limber.	2,210	2,030	4 6	7 3½	5 0	5 3	3	6
Gun and carriage, field, Q.F. 18-pr., Mark I., with limber.	2,200	2,700	4 6	9 11	8 0	5 3	3	6
Wagon, ammunition, Q.F. 18-pr., Marks I. and II., with limber.	2,580	2,340	4 6	7 4½	5 0	5 3	3	6
Howitzer and carriage, field, B.L., 5″, Mark I., with limber, Mark I.	3,100	2,920	4 6	8 2½	5 0	5 2	3	6
Ditto, carriage, Mark I., with limber, Mark II.	2,730	2,920						

Bridge Loads, etc., due to Guns and Vehicles.—*Cont.*

Description of Vehicle.	Weight in lbs. With Full Load, including Men. Fore or Limber Wheels.	Weight in lbs. With Full Load, including Men. Hind or Gun Wheels.	Distances. Front Axle to Hind Legs of Horse.	Distances. Axle to Axle.	Distances. Hind Axle to Fore Legs of Horses following.	Wheel Track Out to Out.	Width of Tyre.	Greatest Projection beyond Track.
			ft. in.	ft. in.	ft. in.	ft. in.	in.	in.
Wagon, ammunition, B.L. 5″ howitzer, Mark I., with limber, Mark I.	3,130	2,860	4 6	7 2¾	5 0	5 2	3	6
Ditto, wagon, Mark II., with limber, Mark II.	2,710	3,560						
Gun and carriage, field, B.L. 60-pr., Mark I., with limber, Mark I. Gun in travelling position.	4,680	7,460	4 6	13 11	8 0	5 2	6	11″ outriggers folded
Ditto. Gun in firing position... ...	2,440	9,830	4 6	13 11	12 6			2′ 3½″ outrigging extended
Wagon, ammunition, B.L. 60-pr., with limber.	2,560	3,630	4 6	7 2½	5 0	5 2½	3	6
Howitzer and carriage, siege, B.L. 6″, 30-cwt., with limber.	2,100	7,820	4 6	8 5	8 0	5 2	4 carriage 3 limber	9
Gun and carriage, field, Q.F. 15-pr., Mark I., converted to long recoil with limber.	2,280	3,200	4 6	9 5	7 6	5 2	3	6

Description of Vehicle.	Weight in lbs. With Full Load, including Men. Fore or Limber Wheels.	Weight in lbs. With Full Load, including Men. Hind or Gun Wheels.	Distances. Front Axle to Hind Legs of Horse.	Distances. Axle to Axle.	Distances. Hind Axle to Fore Legs of Horses following.	Wheel Track Out to Out.	Width of Tyre.	Greatest Projection beyond Track.
			ft. in.	ft. in.	ft. in.	ft. in.	in.	in.
Wagon, ammunition, Q.F. 15-pr., converted to long recoil with limber.	2,250	2,690	4 6	7 5	5 0	5 2	3	6
Gun and carriage, travelling, Q.F. 4·7″, with limber, Mark I.	1,950	8,380	4 6	9 1½	14 6	5 2	6 carriage 3 limber	9½
Gun and carriage, travelling, Q.F. 4·7″, converted Mark I., with limber, converted Mark I.	2,630	9,200	4 6	10 4½	14 6	5 2	6 carriage 3 limber	9
ENGINEER VEHICLES.								
Cart, tool, double, R.E.	2,600	2,600	4 6	8 9	5 0	5 5	2½	4½ each side
Wagons, pontoon	2,200	3,800	4 6	10 5	...	5 8	3	5½ ,,
,, trestle...	2,300	3,700	4 6	10 5	...	5 8	3	5½ ,,
,, spring, Field Troop, R.E...	1,170	1,630	4 6	7 1	5 0	5 5½	3	5 ,,
,, cable	1,220	2,440	4 6	8 4	6 0	5 3½	3	5½ ,,
,, air-line, 6-horsed	3,380	4,120	4 6	9 3	6 0	5 2	3	11 ,,
,, ,, 4-horsed	2,250	2,750	4 6	...	...	5 2	3	11 ,,
Wagon, light spring, R.E.	900	1,350	4 6	6 0	5 0	5 7	2½	4½ ,,

Description of Vehicle.	Weight in lbs. With Full Load, including Men.		Distances.			Wheel Track Out to Out.	Width of Tyre.	Greatest Projection beyond Track.
	Fore or Limber Wheels.	Hind or Gun Wheels.	Front Axle to Hind Legs of Horse.	Axle to Axle.	Hind Axle to Fore Legs of Horses following.			
			ft. in.	ft. in.	ft. in.	ft. in.	in.	in.
Wagon, special, Wireless Company...	2,070	2,730	4 6	7 6	5 0	5 4	3	11 each side
Wagons, boat, Field Troop, R.E. ...	1,660	2,320	4 6	7 0	5 0	5 6	2½	5 ,,
Wagon, reservoir, gas	1,780	2,670	4 6	5 2	5 0	...	2½	...
MEDICAL VEHICLES.								
Wagons, ambulance	2,020	2,820	4 6	7 3½	5 0	5 2	2½	5 ,,
,, ambulance, light	...	...	...	...	...	...	...	...
MISCELLANEOUS.								
Wagon, bread and meat	3,120	4,680	4 6	6 6	5 0	5 7	2½	4½ ,,
,, printing	1,860	2,610	4 6	6 3	5 0	5 5	3	4½ ,,
HIRED TRANSPORT.								
Wagons, 4-horsed, Auxiliary Transport Company.	2,150	3,000	4 6	5 0	5 0	...	...	...
Carts, 2-horsed, Auxiliary Transport Company.	...	2,500	4 6	...	5 0	5 6	3	4½ ,,
Heavy farm wains	4,800	4,800	4 6	5 6	6 0	5 5	2½	6½ ,,
Large delivery vans	5,000	7,000	4 0	5 6	7 0	5 7½	2	4½ ,,

Bridge Loads, etc., due to Guns and Vehicles.—*Cont.*

Description of Vehicle.	Weight in lbs. With Full Load, including Men.		Distances.			Wheel Track Out to Out.	Width of Tyre.	Greatest Projection beyond Track.
	Fore or Limber Wheels.	Hind or Gun Wheels.	Front Axle to Hind Legs of Horse.	Axle to Axle.	Hind Axle to Fore Legs of Horses following.			
Motor Vehicles.				ft. in.	ft. in.	ft. in.	ft. in.	in.
Two-seated motor car	1,000	1,350	...	7 10	...	4 5	0 3 8	each side
Heavy touring motor car	2,500	4,200	...	11 0	...	5 4	0 4 4	,,
30-cwt. A.S.C. lorry (petrol) or motor ambulance.	4,000	7,900	...	11 6	...	6 5	0 9½* 2	,,
3-ton A.S.C. lorry (petrol)	4,550	10,950	...	13 7	...	6 5	0 11* 2	,,
Light steam tractor (one-truck engine)	4,500	10,000	...	8 0	...	5 10	1 0 2	,,
Medium steam tractor (two-truck engine).	10,600	21,000	...	9 11	...	7 0	1 4	...
Heavy steam tractor (three-truck engine).	11,200	24,700	...	11 1	...	7 5	1 4	...
Mobile workshop truck...	9,000	9,000	...	10 2	...	5 11	0 9½ 9½	,,
5-ton truck	8,400	8,400	...	8 7	...	5 5	0 8½ 8	,,
Thorneycroft lorry	6,000	12,000	...	10 6	...	6 7	0 11	...
Trailer for ditto	4,400	4,400	...	8 10	...	6 4	0 4½ 3½	,,
Heavy commercial lorry	7,100	17,700	...	13 0	...	6 8½	0 8	...
Foden steamer, 5 ton	8,960	17,920	...	14 0	...	6 7	...	...

* These are twin tyres, rubber. Actual width of tyre in contact with roadway is 4" to 6" according to age of tyres.

	Sine.	Diff.	Tan.	Diff.	Cotan.	Diff.	Cosine.	Diff.	
0°	Zero.	for 1″	Zero.	for 1″	∞	for 1″	1·0000	0	90
	·000		·000			∞			″
1″	00485		00485		206265		1·00000	0	59
5″	02424		02424		41253	41253	1·00000	0	55
10″	04848		04848		20626	4125	1·00000	0	50
20″	09696	485	09696	485	10313	1031	1·00000	0	40
30″	14544		14544		6875·5	343·8	1·00000	0	30
40″	19393		19393		5156·6	171·9	1·00000	0	20
50″	24242		24242		4125·3	103·1	1·00000	0	10
						68·8		for 10′	
1′	·00029	for 1′	·00029	for 1′	3437·7	for 1′	1·00000	1	59
10′	·00291		·00291		343·77	343·77	·99999	1	50
20′	·00582		·00582		171·89	17·188	·99998	2	40
30′	·00873	29	·00873	29	114·59	5·730	·99996	3	30
40′	·01164		·01164		85·940	2·865	·99993	4	20
50′	·01454		·01455		68·750	1·719	·99989		10
		for 10′		for 10′		1·1460			
°						for 10″			°
1	·01745		·01746		57·290	4·7756	·99985	4	89
2	·03490	291	·03492	291	28·636	1·5925	·99939	8	88
3	·05234	291	·05241	292	19·081	7967	·99863	13	87
4	·06976	290	·06993	292	14·301	4784	·99756	18	86
5	·08716	290	·08749	293	11·430	3193	·99619	23	85
6	·10453	290	·10510	294	9·5144	2284	·99452	28	84
7	·12187	289	·12278	295	8·1443	1715	·99255	33	83
8	·13917	288	·14054	296	7·1154	1336	·99027	38	82
9	·15643	288	·15838	297	6·3138	1071	·98769	43	81
10	·17365	287	·17633	299	5·6713		·98481	48	80
						878			
11	·19081	286	·19438	301	5·1446	733	·98163	53	79
12	·20791	285	·21256	303	4·7046	622	·97815	58	78
13	·22495	284	·23087	305	4·3315	535	·97437	63	77
14	·24192	283	·24933	308	4·0108	465	·97030	68	76
15	·25882	282	·26795	310	3·7321	408	·96593	73	75
		280		313				78	
	Cosine.	Diff.	Cotan.	Diff.	Tan.	Diff.	Sine.	Diff.	

Natural Sines, Tangents, etc.—*Cont.*

	Sine.	Diff.	Tan.	Diff.	Cotan.	Diff.	Cosine.	Diff.	
0									
16	·27564	280	·28675	313	3·4874	408	·96126	78	74
17	·29237	279	·30573	316	3·2709	361	·95630	83	73
18	·30902	278	·32492	320	3·0777	322	·95106	87	72
19	·32557	276	·34433	324	2·9042	289	·94552	92	71
20	·34202	274	·36397	327	2·7475	261	·93969	97	70
21	·35837	273	·38386	332	2·6051	237	·93358	102	69
22	·37461	271	·40403	336	2·4751	217	·92718	107	68
23	·39073	269	·42447	341	2·3559	199	·92050	111	67
24	·40674	267	·44523	346	2·2460	183	·91355	116	66
25	·42262	265	·46631	351	2·1445	169	·90631	121	65
26	·43837	263	·48773	357	2·0503	157	·89879	125	64
27	·45399	260	·50953	363	1·9626	146	·89101	130	63
28	·46947	258	·53171	370	1·8807	137	·88295	134	62
29	·48481	256	·55431	377	1·8040	128	·87462	139	61
30	·50000	253	·57735	384	1·7321	120	·86603	143	60
31	·51504	251	·60086	392	1·6643	113	·85717	148	59
32	·52992	248	·62487	400	1·6003	107	·84805	152	58
33	·54464	245	·64941	409	1·5399	101	·83867	156	57
34	·55919	243	·67451	418	1·4826	96	·82904	161	56
35	·57358	240	·70021	428	1·4281	91	·81915	165	55
36	·58779	237	·72654	439	1·3764	86	·80902	169	54
37	·60182	234	·75355	450	1·3270	82	·79864	173	53
38	·61566	231	·78129	462	1·2799	79	·78801	177	52
39	·62932	228	·80978	475	1·2349	75	·77715	181	51
40	·64279	225	·83910	489	1·1918	72	·76604	185	50
41	·65606	221	·86929	503	1·1504	69	·75471	189	49
42	·66913	218	·90040	519	1·1106	66	·74314	193	48
43	·68200	215	·93252	535	1·0724	64	·73135	197	47
44	·69466	211	·96569	553	1·0355	62	·71934	200	46
45	·70711	208	1·00000	572	1·0000	59	·70711	204	45
	Cosine.	Diff.	Cotan.	Diff.	Tan.	Diff.	Sine.	Diff.	

Natural Cosecants and Secants.

	Cosecs.	Diff.	Secants.	Diff.			Cosecs.	Diff.	Secants.	Diff.	
				fo. 10′				for 10′		for 10′	
0	∞	for 1″ ∞	1·0000	0	90°	0				8	
1″	206265	41253	1·0000	0	59″	16	3·6280	393	1·0403	9	74
5″	41253	4125	1·0000	0	55″	17	3·4203	346	1·0457	10	73
10″	20625	1031·3	1·0000	0	50″	18	3·2361	307	1·0515	10	72
20″	10313	343·75	1·0000	0	40″	19	3·0716	274	1·0576	11	71
30″	6875·5	171·89	1·0000	0	30″	20	2·9238	246	1·0642		70
40″	5156·6	103·13	1·0000	0	20″					12	
50″	4125·3	68·76	1·0000	0	10″	21	2·7904	222	1·0711	12	69
		for 1′				22	2·6695	202	1·0785	13	68
1′	3437·7	343·77	1·0000	0	59′	23	2·5593	184	1·0864	14	67
10′	343·78	17·189	1·0000	0	50′	24	2·4586	168	1·0946	15	66
20′	171·89	5·730	1·0000	0	40′	25	2·3662	157	1·1034	15	65
30′	114·59	2·8644	1·0000	0	30′	26	2·2812	142	1·1126	16	64
40′	85·946	1·7189	1·0001	0	20′	27	2·2027	131	1·1223	17	63
50′	68·757	1·1458	1·0001	0	10′	28	2·1301	121	1·1326	18	62
		for 10′				29	2·0627	112	1·1434	19	61
0					0	30	2·0000	105	1·1547		60
1	57·299	4·774	1·0002	1	89					20	
2	28·654	1·591	1·0006	1	88	31	1·9416	97	1·1666	21	59
3	19·107	·795	1·0014	2	87	32	1·8871	91	1·1792	22	58
4	14·336	·477	1·0024	2	86	33	1·8361	85	1·1924	23	57
5	11·474	·3179	1·0038	3	85	34	1·7883	80	1·2062	24	56
6	9·5668	2269	1·0055	3	84	35	1·7434	75	1·2208	26	55
7	8·2055	1700	1·0075	4	83	36	1·7013	70	1·2361	27	54
8	7·1853	1321	1·0098	5	82	37	1·6616	66	1·2521	28	53
9	6·3925	1056	1·0125	5	81	38	1·6243	62	1·2690	30	52
10	5·7588	863	1·0154	6	80	39	1·5890	59	1·2868	31	51
						40	1·5557	56	1·3054		50
11	5·2408		1·0187	6	79	41	1·5243	52	1·3250	33	49
12	4·8097	719	1·0223	7	78	42	1·4945	50	1·3456	34	48
13	4·4454	607	1·0263	7	77	43	1·4663	47	1·3673	36	47
14	4·1336	520	1·0306	7	76	44	1·4396	45	1·3902	38	46
15	3·8637	456	1·0353	8	75	45	1·4142	42	1·4142	40	45
		393									

Secants.	Diff.	Cosecs.	Diff.		Secants.	Diff.	Cosecs.	Diff.	

Coversine = 1 − sine. Versine = 1 − cosine.

Logarithms of Numbers from 0 to 1000.

No.	0	1	2	3	4	5	6	7	8	9	D
0	0	00000	30103	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01284	01703	02119	02531	02938	03342	03743	415
11	04139	04532	04922	05308	05690	06070	06446	06819	07188	07555	379
12	07918	08279	08636	08991	09342	09691	10037	10380	10721	11059	344
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301	323
14	14613	14922	15229	15534	15836	16137	16435	16732	17026	17319	298
15	17609	17898	18184	18469	18752	19033	19312	19590	19866	20140	281
16	20412	20683	20952	21219	21484	21748	22011	22272	22531	22789	264
17	23045	23300	23553	23805	24055	24304	24551	24797	25042	25285	249
18	25527	25768	26007	26245	26482	26717	26951	27184	27416	27646	234
19	27875	28103	28330	28556	28780	29003	29226	29447	29667	29885	222
20	30103	30320	30535	30750	30963	31175	31387	31597	31806	32015	212
21	32222	32428	32634	32838	33041	33244	33445	33646	33846	34044	202
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984	193
23	36173	36361	36549	36736	36922	37107	37291	37475	37658	37840	185
24	38021	38202	38382	38561	38739	38917	39094	39270	39445	39620	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	170
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975	164
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560	158
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090	153
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567	148
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48996	143
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379	138
32	50515	50651	50786	50920	51055	51189	51322	51455	51587	51720	134
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020	130
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54238	126
35	54407	54531	54654	54777	54900	55023	55145	55267	55388	55509	122
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703	119
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57864	116
38	57978	58093	58206	58320	58433	58546	58659	58771	58883	58995	113
39	59106	59218	59329	59439	59550	59660	59770	59879	59988	60097	110
40	60206	60314	60423	60531	60638	60746	60853	60959	61066	61172	107
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221	104
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246	102
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246	99
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225	98
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181	96
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117	95
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034	92
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931	90
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810	88
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672	86

LOGARITHMS OF NUMBERS FROM 0 TO 1000.—*Cont.*

N.	0	1	2	3	4	5	6	7	8	9	D
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517	84
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346	82
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159	81
54	73239	73320	73400	73480	73560	73640	73719	73799	73878	73957	80
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741	78
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511	77
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268	75
58	76343	76418	76492	76567	76641	76716	76790	76864	76938	77012	74
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743	73
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462	72
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169	71
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865	70
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550	69
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224	68
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	81889	67
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543	66
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187	64
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822	63
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448	63
70	84510	84572	84634	84696	84757	84819	84880	84942	85003	85065	62
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673	61
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273	60
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864	59
74	86923	86982	87040	87099	87157	87216	87274	87332	87390	87448	58
75	87506	87564	87622	87680	87737	87795	87852	87910	87967	88024	57
76	88081	88138	88196	88252	88309	88366	88423	88480	88536	88593	57
77	88649	88705	88762	88818	88874	88930	88986	89042	89098	89154	56
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708	55
79	89763	89818	89873	89927	89982	90037	90091	90146	90200	90255	54
80	90309	90363	90417	90472	90526	90580	90634	90687	90741	90795	54
81	90849	90902	90956	91009	91062	91116	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855	53
83	91908	91960	92012	92065	92117	92169	92221	92273	92324	92376	52
84	92428	92480	92531	92583	92634	92686	92737	92788	92840	92891	51
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	93399	51
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902	50
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94399	49
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376	48
90	95424	95472	95521	95569	95617	95665	95713	95761	95809	95856	48

Logarithms of Numbers from 0 to 1000.—*Cont.*

Nos.	0	1	2	3	4	5	6	7	8	9	D
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332	48
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802	47
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267	47
94	97313	97359	97405	97451	97497	97543	97589	97635	97681	97727	46
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182	46
96	98227	98272	98318	98363	98408	98453	98498	98543	98588	98632	45
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078	45
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520	44
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957	44

Diff.	Proportional Parts.								
420	42	84	126	168	210	252	294	336	378
390	39	78	117	156	195	234	273	312	351
360	36	72	108	144	180	216	252	288	324
330	33	66	99	132	165	198	231	264	297
300	30	60	90	120	150	180	210	240	270
270	27	54	81	108	135	162	189	216	243
240	24	48	72	96	120	144	168	192	216
210	21	42	63	84	105	126	147	168	189
180	18	36	54	72	90	108	126	144	162
150	15	30	45	60	75	90	105	120	135
120	12	24	36	48	60	72	84	96	108
90	9	18	27	36	45	54	63	72	81
60	6	12	18	24	30	36	42	48	54
30	3	6	9	12	15	18	21	24	27
10	1	2	3	4	5	6	7	8	9

Gauge Points.

The following multipliers will be found useful in shortening calculations :—

Area of square × ·7854 = area of inscribed circle.

Cub. content of cub. × ·5236 = cub. content of inscribed globe.

Acres × ·0015625 = square miles.

Links × 1·515 = feet.

Cubic feet × ·02857 = tons displacement.

For Wrought Iron or Steel.

Cubic inches × 400 = cwt.
Square inches section × 10 = lbs. per yd.
Thickness of plare in inches × 40 = lbs. per sq. ft.
Weight of rails per yd. × ·7857 = tons per mile.

Manual Labour.

A man lifting a weight with both hands exerts an absolute average force of 286lbs. Best position is erect, with shoulders slightly inclined. Greatest load a man can carry on his shoulders is generally reckoned at 330lbs. The maximum horizontal pull that the average man can exert is 110lbs. The average force of a horse = 5 men. Horse power as ordinarily applied to machinery, etc., means the raising of 33,000lbs. through a distance of 1′.

Square Roots and Cube Roots.

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
1	1·0	1·0	31	5·56776	3·1414	61	7·81025	3·9365
2	1·41421	1·2599	32	5·65685	3·1748	62	7·87401	3·9579
3	1·73205	1·4422	33	5·74456	3·2075	63	7·93725	3·9791
4	2·0	1·5874	34	5·83095	3·2396	64	8·0	4·0
5	2·23607	1·7100	35	5·91608	3·2711	65	8·06226	4·0207
6	2·44949	1·8171	36	6·0	3·3019	66	8·12404	4·0412
7	2·64575	1·9129	37	6·08276	3·3322	67	8·18535	4·0615
8	2·82843	2·0	38	6·16441	3·3620	68	8·24621	4·0817
9	3·0	2·0801	39	6·245	3·3912	69	8·30662	4·1016
10	3·16228	2·1544	40	6·32456	3·4200	70	8·36660	4·1213
11	3·31662	2·2240	41	6·40312	3·4482	71	8·42615	4·1408
12	3·46410	2·2894	42	6·48074	3·4760	72	8·48528	4·1602
13	3·60555	2·3513	43	6·55744	3·5034	73	8·54400	4·1793
14	3·74166	2·4101	44	6·63325	3·5303	74	8·60233	4·1983
15	3·87298	2·4662	45	6·70820	3·5569	75	8·66025	4·2172
16	4·0	2·5198	46	6·78233	3·5830	76	8·71780	4·2358
17	4·12311	2·5713	47	6·85565	3·6088	77	8·77496	4·2543
18	4·24264	2·6207	48	6·92820	3·6342	78	8·83176	4·2727
19	4·35890	2·6684	49	7·0	3·6593	79	8·88819	4·2908
20	4·47214	2·7144	50	7·07107	3·6840	80	8·91427	4·3089
21	4·58258	2·7589	51	7·14143	3·7084	81	9·0	4·3267
22	4·69042	2·8020	52	7·21110	3·7325	82	9·05539	4·3445
23	4·79583	2·8439	53	7·28011	3·7563	83	9·11043	4·3621
24	4·89898	2·8845	54	7·34847	3·7798	84	9·16515	4·3795
25	5·0	2·9240	55	7·4162	3·8030	85	9·21954	4·3968
26	5·09902	2·9625	56	7·48331	3·8259	86	9·27362	4·4140
27	5·19615	3·0	57	7·54983	3·8485	87	9·32738	4·4310
28	5·29150	3·0366	58	7·61577	3·8709	88	9·38083	4·4480
29	5·38516	3·0723	59	7·68115	3·8930	89	9·43398	4·4647
30	5·47723	3·1072	60	7·74597	3·9149	90	9·48683	4·4814

Square Roots and Cube Roots.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
91	9·53939	4·4979	121	11·0	4·9461	151	12·28821	5·3251
92	9·59166	4·5144	122	11·04536	4·9597	152	12·32883	5·3368
93	9.64365	4·5307	123	11·09054	4·9732	153	12·36932	5·3485
94	9·69536	4·5468	124	11·13553	4·9866	154	12·40967	5·3601
95	9·74679	4·5629	125	11·18034	5·0	155	12·44990	5·3717
96	9·79796	4·5789	126	11·22497	5·0133	156	12·49000	5·3832
97	9·84886	4·5947	127	11·26943	5·0265	157	12·52996	5·3947
98	9·89949	4·6104	128	11·31371	5·0397	158	12·56981	5·4061
99	9·94987	4·6261	129	11·35782	5·0528	159	12·60952	5·4175
100	10·0	4·6416	130	11·40188	5·0652	160	12·64911	5·4288
101	10·04988	4·6570	131	11·44552	5·0788	161	12·68858	5·4401
102	10·09950	4·6723	132	11·48913	5·0916	162	12·72792	5·4514
103	10·14889	4·6875	133	11·53256	5·1045	163	12·76715	5·4626
104	10·19804	4·7027	134	11·57584	5·1172	164	12·80625	5·4737
105	10·24695	4·7177	135	11·61895	5·1299	165	12·84523	5·4848
106	10·29563	4·7326	136	11·6619	5·1426	166	12·88410	5·4959
107	10·34408	4·7475	137	11·70470	5·1551	167	12·92285	5·5069
108	10·39230	4·7622	138	11·74734	5·1676	168	12·96148	5·5178
109	10·44031	4·7769	139	11·78983	5·1801	169	13·0	5·5288
110	10·48809	4·7914	140	11·8322	5·1925	170	13·03840	5·5397
111	10·53565	4·8059	141	11·87434	5·2048	171	13·07670	5·5505
112	10·58301	4·8203	142	11·9164	5·2171	172	13·11488	5·5613
113	10·63015	4·8346	143	11·9583	5·2293	173	13·15295	5·5721
114	10·67708	4·8488	144	12·0	5·2415	174	13·19091	5·5828
115	10·72381	4·8629	145	12·0416	5·2536	175	13·22876	5·5934
116	10·77033	4·8770	146	12·08305	5·2656	176	13·26650	5·6041
117	10·81665	4·8910	147	12·12436	5·2776	177	13·30413	5·6147
118	10·86278	4·9049	148	12·16553	5·2896	178	13·34166	5·6252
119	10·90871	4·9187	149	12·20656	5·3015	179	13·37909	5·6357
120	10·95445	4·9324	150	12·24745	5·3133	180	13·41641	5·6462

SQUARE ROOTS AND CUBE ROOTS.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
181	13·45362	5·6567	211	14·5258	5·9533	241	15·5242	6·2231
182	13·49074	5·6671	212	14·5602	5·9627	242	14·5563	6·2317
183	13·52775	5·6774	213	14·5945	5·9721	243	15·5885	6·2403
184	13·56466	5·6877	214	14·6287	5·9814	244	15·6205	6·2488
185	13·60147	5·6980	215	14·6629	5·9907	245	15·6525	6·2573
186	13·63818	5·7083	216	14·6969	6·0	246	15·6844	6·2658
187	13·67479	5·7185	217	14·7309	6·0092	247	15·7162	6·2743
188	13·71131	5·7287	218	14·7648	6·0185	248	15·7480	6·2828
189	13·74773	5·7388	219	14·7986	6·0277	249	15·7797	6·2912
190	13·78405	5·7489	220	14·8324	6·0368	250	15·8114	6·2996
191	13·82028	5·7590	221	14·8661	6·0459	251	15·8430	6·3080
192	13·85641	5·7689	222	14·8997	6·0550	252	15·8745	6·3164
193	13·89244	5·7790	223	14·9332	6·0641	253	15·9060	6·3247
194	13·92839	5·7890	224	14·9666	6·0732	254	15·9374	6·3330
195	13·96424	5·7988	225	15·0	6·0822	255	15·9687	6·3413
196	14·0	5·8088	226	15·0333	6·0912	256	16·0	6·3496
197	14·03567	5·8186	227	15·0665	6·1002	257	16·0312	6·3579
198	14·07125	5·8285	228	15·0997	6·1091	258	16·0624	6·3661
199	14·10674	5·8383	229	15·1327	6·1180	259	16·0935	6·3743
200	14·14214	5·8480	230	15·1658	6·1269	260	16·1245	6·3825
201	14·1774	5·8578	231	15·1987	6·1358	261	16·1555	6·3907
202	14·2127	5·8675	232	15·2315	6·1446	262	16·1864	6·3988
203	14·2478	5·8771	233	15·2643	6·1534	263	16·2173	6·4070
204	14·2829	5·8868	234	15·2971	6·1622	264	16·2481	6·4151
205	14·3178	5·8964	235	15·3297	6·1710	265	16·2788	6·4232
206	14·3527	5·9059	236	15·3623	6·1797	266	16·3095	6·4312
207	14·3875	5·9155	237	15·3948	6·1885	267	16·3401	6·4393
208	14·4222	5·9250	238	15·4272	6·1972	268	16·3707	6·4473
209	14·4568	5·9345	239	15·4596	6·2058	269	16·4012	6·4553
210	14·4914	5·9439	240	15·4919	6·2145	270	16·4317	6·4633

SQUARE ROOTS AND CUBE ROOTS.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
271	16·4621	6·4713	301	17·3494	6·702	331	18·1934	6·917
272	16·4924	6·4792	302	17·3781	6·709	332	18·2209	6·924
273	16·5227	6·4872	303	17·4069	6·717	333	18·2483	6·931
274	16·5529	6·4951	304	17·4356	6·724	334	18·2757	6·938
275	16·5831	6·5030	305	17·4642	6·731	335	18·3030	6·945
276	16·6132	6·5108	306	17·4929	6·739	336	18·3303	6·952
277	16·6433	6·5187	307	17·5214	6·746	337	18·3576	6·959
278	16·6733	6·5265	308	17·5499	6·753	338	18·3848	6·966
279	16·7033	6·5343	309	17·5784	6·761	339	18·4120	6·973
280	16·7332	6·5421	310	17·6068	6·768	340	18·4391	6·980
281	16·7631	6·550	311	17·6352	6·775	341	18·4662	6·986
282	16·7929	6·558	312	17·6635	6·782	342	18·4932	6·993
283	16·8226	6·565	313	17· 698	6·790	343	18·5203	7·0
284	16·8523	6·573	314	17·7200	6·797	344	18·5472	7·007
285	16·8819	6·581	315	17·7482	6·804	345	18·5742	7·014
286	16·9115	6·589	316	17·7764	6·811	346	18·6011	7·020
287	16·9411	6·596	317	17·8045	6·818	347	18·6279	7·027
288	16·9706	6·604	318	17·8326	6·826	348	18·6548	7·034
289	17·0	6·611	319	17·8606	6·833	349	18·6815	7·041
290	17·0294	6·619	320	17·8885	6·840	350	18·7083	7·047
291	17·0587	6·627	321	17·9165	6·847	351	18·7350	7·054
292	17·0880	6·634	322	17·9444	6·854	352	18·7617	7·061
293	17·1172	6·642	323	17·9722	6·861	353	18·7883	7·067
294	17·1464	6·649	324	18·0	6·868	354	18·8149	7·074
295	17·1756	6·657	325	18·0278	6·875	355	18·8414	7·081
296	17·2047	6·664	326	18·0555	6·882	356	18·8680	7·087
297	17·2337	6·672	327	18·0831	6·889	357	18·8944	7·094
298	17·2627	6·679	328	18·1108	6·896	358	18·9209	7·101
299	17·2916	6·687	329	18·1384	6·903	359	18·9473	7·107
300	17·3205	6·694	330	18·1659	6·910	360	18·9737	7·114

Square Roots and Cube Roots.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
361	19·0	7·120	391	19·7737	7·312	421	20·5183	7·495
362	19·0263	7·127	392	19·7990	7·319	422	20·5426	7·501
363	19·0526	7·133	393	19·8242	7·325	423	20·5670	7·507
364	19·0788	7·140	394	19·8494	7·331	424	20·5913	7·513
365	19·1050	7·147	395	19·8746	7·337	425	20·6155	7·518
366	19·1311	7·153	396	19·8997	7·343	426	20·6398	7·524
367	19·1572	7·160	397	19·9249	7·350	427	20·6640	7·530
368	19·1833	7·166	398	19·9499	7·356	428	20·6882	7·536
369	19·2094	7·173	399	19·9750	7·362	429	20·7123	7·542
370	19·2354	7·179	400	20·0	7·368	430	20·7364	7·548
371	19·2614	7·186	401	20·0250	7·374	431	20·7605	7·554
372	19·2873	7·192	402	20·0499	7·380	432	20·7846	7·560
373	19·3132	7·198	403	20·0749	7·386	433	20·8087	7·565
374	19·3391	7·205	404	20·0998	7·393	434	20·8327	7·571
375	19·3649	7·211	405	20·1246	7·399	435	20·8567	7·577
376	19·3907	7·218	406	20·1494	7·405	436	20·8806	7·583
377	19·4165	7·224	407	20·1742	7·411	437	20·9045	7·589
378	19·4422	7·230	408	20·1990	7·417	438	20·9284	7·594
379	19·4679	7·237	409	20·2237	7·423	439	20·9523	7·600
380	19·4936	7·243	410	20·2485	7·429	440	20·9762	7·606
381	19·5192	7·249	411	20·2731	7·435	441	21·0	7·612
382	19·5448	7·256	412	20·2978	7·441	442	21·024	7·617
383	19·5704	7·262	413	20·3224	7·447	443	21·048	7·623
384	19·5959	7·268	414	20·3470	7·453	444	21·071	7·629
385	19·6214	7·275	415	20·3715	7·459	445	21·095	7·635
386	19·6469	7·281	416	20·3961	7·465	446	21·119	7·640
387	19·6723	7·287	417	20·4206	7·471	447	21·142	7·646
388	19·6977	7·294	418	20·4450	7·477	448	21·166	7·652
389	19·7231	7.300	419	20·4695	7·483	449	21·190	7·657
390	19·7484	7·306	420	20·4939	7·489	450	21·213	7·663

Square Roots and Cube Roots.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
451	21·237	7·669	481	21·932	7·835	511	22·605	7·995
452	21·260	7·674	482	21·954	7·841	512	22·627	8·0
453	21·284	7·680	483	21·977	7·846	513	22·649	8·005
454	21·307	7·686	484	22·0	7·851	514	22·672	8·010
455	21·331	7·691	485	22·023	7·857	515	22·694	8·016
456	21·354	7·697	486	22·045	7·862	516	22·716	8·021
457	21·378	7·703	487	22·068	7·868	517	22·738	8·026
458	21·401	7·708	488	22·091	7·873	518	22·760	8·031
459	21·424	7·714	489	22·113	7·878	519	22·782	8·036
460	21·448	7·719	490	22·136	7·884	520	22·803	8·041
461	21·471	7·725	491	22·159	7·889	521	22·825	8·047
462	21·494	7·731	492	22·181	7·894	522	22·847	8·052
463	21·517	7·736	493	22·204	7·900	523	22·869	8·057
464	21·541	7·742	494	22·226	7·905	524	22·891	8·062
465	21·564	7·747	495	22·249	7·910	525	22·913	8·067
466	21·587	7·753	496	22·271	7·916	526	22·935	8·072
467	21·610	7·758	497	22·293	7·921	527	22·956	8·077
468	21·633	7·764	498	22·316	7·926	528	22·978	8·082
469	21·656	7·769	499	22·338	7·932	529	23·0	8·088
470	21·679	7·775	500	22·361	7·937	530	23·022	8·093
471	21·703	7·780	501	22·383	7·942	531	23·043	8·098
472	21·726	7·786	502	22·405	7·948	532	23·065	8·103
473	21·749	7·791	503	22·428	7·953	533	23·087	8·108
474	21·772	7·797	504	22·450	7·958	534	23·108	8·113
475	21·794	7·802	505	22·472	7·963	535	23·130	8·118
476	21·817	7·808	506	22·494	7·969	536	23·152	8·123
477	21·840	7·813	507	22·517	7·974	537	23·173	8·128
478	21·863	7·819	508	22·539	7·979	538	23·195	8·133
479	21·886	7·824	509	22·561	7·984	539	23·216	8·138
480	21·909	7·830	510	22·583	7·990	540	23·238	8·143

SQUARE ROOTS AND CUBE ROOTS.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
541	23·259	8·148	571	23·896	8·296	601	24·515	8·439
542	23·281	8·153	572	23·917	8·301	602	24·536	8·444
543	23·302	8·158	573	23·937	8·306	603	24·556	8·448
544	23·324	8·163	574	23·958	8·311	604	24·576	8·453
545	23·345	8·168	575	23·979	8·316	605	24·597	8·458
546	23·367	8·173	576	24·0	8·320	606	24·617	8·462
547	23·388	8·178	577	24·021	8·325	607	24·637	8·467
548	23·409	8·183	578	24·042	8·330	608	24·658	8·472
549	23·431	8·188	579	24·062	8·335	609	24·678	8·476
550	23·452	8·193	580	24·083	8·340	610	24·698	8·481
551	23·473	8·198	581	24·104	8·344	611	24·718	8·486
552	23·495	8·203	582	24·125	8·349	612	24·739	8·490
553	23·516	8·208	583	24·145	8·354	613	24·759	8·495
554	23·537	8·213	584	24·166	8·359	614	24·779	8·499
555	23·558	8·218	585	24·187	8·363	615	24·799	8·504
556	23·580	8·223	586	24·207	8·368	616	24·819	8·509
557	23·601	8·228	587	24·228	8·373	617	24·839	8·513
558	23·622	8·233	588	24·249	8·378	618	24·860	8·518
559	23·643	8·238	589	24·269	8·382	619	24·880	8·522
560	23·664	8·243	590	24·290	8·387	620	24·900	8·527
561	23·685	8·247	591	24·310	8·392	621	24·920	8·532
562	23·707	8·252	592	24·331	8·397	622	24·940	8·536
563	23·728	8·257	593	24·352	8·401	623	24·960	8·541
564	23·749	8·262	594	24·372	8·406	624	24·980	8·545
565	23·770	8·267	595	24·393	8·411	625	25·0	8·550
566	23·791	8·272	596	24·413	8·416	626	25·020	8·554
567	23·812	8·277	597	24·434	8·420	627	25·040	8·559
568	23·833	8·282	598	24·454	8·425	628	25·060	8·564
569	23·854	8·286	599	24·474	8·430	629	25·080	8·568
570	23·875	8·291	600	24·495	8·434	630	25·100	8·573

SQUARE ROOTS AND CUBE ROOTS.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
631	25·120	8·577	661	25·710	8·711	691	26·287	8·841
632	25·140	8·582	662	25·729	8·715	692	26·306	8·845
633	25·159	8·586	663	25·749	8·720	693	26·325	8·849
634	25·179	8·591	664	25·768	8·724	694	26·344	8·854
635	25·199	8·595	665	25·788	8·729	695	26·363	8·858
636	25·219	8·600	666	25·807	8·733	696	26·382	8·862
637	25·239	8·604	667	25·826	8·737	697	26·401	8·866
638	25·259	8·609	668	25·846	8·742	698	26·420	8·871
639	25·278	8·613	669	25·865	8·746	699	26·439	8·875
640	25·298	8·618	670	25·884	8·750	700	26·458	8·879
641	25·318	8·622	671	25·904	8·755	701	26·476	8·883
642	25·338	8·627	672	25·923	8·759	702	26·495	8·887
643	25·357	8·631	673	25·942	8·763	703	26·514	8·892
644	25·377	8·636	674	25·962	8·768	704	26·533	8·896
645	25·397	8·640	675	25·981	8·772	705	26·552	8·900
646	25·417	8·645	676	26·0	8·776	706	26·571	8·904
647	25·436	8·649	677	26·019	8·781	707	26·589	8·909
648	25·456	8·653	678	26·038	8·785	708	26·608	8·913
649	25·475	8·658	679	26·058	8·789	709	26·627	8·917
650	25·495	8·662	680	26·077	8·794	710	26·646	8·921
651	25·515	8·667	681	26·096	8·798	711	26·665	8·925
652	25·534	8·671	682	26·115	8·802	712	26·683	8·929
653	25·554	8·676	683	26·134	8·807	713	26·702	8·934
654	25·573	8·680	684	26·153	8·811	714	26·721	8·938
655	25·593	8·685	685	26·172	8·815	715	26·739	8·942
656	25·612	8·689	686	26·192	8·819	716	26·758	8·940
657	25·632	8·693	687	26·211	8·824	717	26·777	8·950
658	25·652	8·698	688	26·230	8·828	718	26·796	8·955
659	25·671	8·702	689	26·249	8·832	719	26·814	8·959
660	25·690	8·707	690	26·268	8·837	720	26·833	8·963

Square Roots and Cube Roots.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
721	26·851	8·967	751	27·404	9·090	781	27·946	9·209
722	26·870	8·971	752	27·423	9·094	782	27·964	9·213
723	26·889	8·975	753	27·441	9·098	783	27·982	9·217
724	26·907	8·979	754	27·459	9·102	784	28·0	9·221
725	26·926	8·983	755	27·477	9·106	785	28·018	9·225
726	26·944	8·988	756	27·495	9·110	786	28·036	9·229
727	26·963	8·992	757	27·514	9·114	787	28·054	9·233
728	26·981	8·996	758	27·532	9·118	788	28·071	9·237
729	27·0	9·0	759	27·550	9·122	789	28·089	9·240
730	27·019	9·004	760	27·568	9·126	790	28·107	9·244
731	27·037	9·008	761	27·586	9·130	791	28·125	9·248
732	27·055	9·012	762	27·604	9·134	792	28·142	9·252
733	27·074	9·016	763	27·622	9·138	793	28·160	9·256
734	27·092	9·021	764	27·641	9·142	794	28·178	9·260
735	27·117	9·025	765	27·659	9·146	795	28·196	9·264
736	27·129	9·029	766	27·677	9·150	796	28·213	9·268
737	27·148	9·033	767	27·695	9·154	797	28·231	9·272
738	27·166	9·037	768	27·713	9·158	798	28·249	9·275
739	27·185	9·041	769	27·731	9·162	799	28·267	9·279
740	27·203	9·045	770	27·749	9·166	800	28·284	9·283
741	27·221	9·049	771	27·767	9·170	801	28·302	9·287
742	27·240	9·053	772	27·785	9·174	802	28·320	9·291
743	27·258	9·057	773	27·803	9·178	803	28·337	9·295
744	27·276	9·061	774	27·821	9·181	804	28·355	9·299
745	27·295	9·065	775	27·839	9·185	805	28·373	9·302
746	27·313	9·069	776	27·857	9·189	806	28·390	9·306
747	27·331	9·073	777	27·875	9·193	807	28·408	9·310
748	27·350	9·078	778	27·893	9·197	808	28·425	9·314
749	27·368	9·082	779	27·911	9·201	809	28·443	9·318
750	27·386	9·086	780	27·928	9·205	810	28·460	9·322

Square Roots and Cube Roots.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
811	28·478	9·326	841	29·0	9·439	871	29·513	9·550
812	28·496	9·329	842	29·017	9·443	872	29·530	9·554
813	28·513	9·333	843	29·034	9·447	873	29·547	9·557
814	28·531	9·337	844	29·052	9·450	874	29·563	9·561
815	28·548	9·341	845	29·069	9·454	875	29·580	9·565
816	28·566	9·345	846	29·086	9·458	876	29·597	9·568
817	28·583	9·348	847	29·103	9·462	877	29·614	9·572
818	28·601	9·352	848	29·120	9·465	878	29·631	9·576
819	28·618	9·356	849	29·138	9·469	879	29·648	9·579
820	28·636	9·360	850	29·155	9·473	880	29·665	9·583
821	28·653	9·364	851	29·172	9·476	881	29·682	9·586
822	28·671	9·367	852	29·189	9·480	882	29·698	9·590
823	28·688	9·371	853	29·206	9·484	883	29·715	9·594
824	28·705	9·375	854	29·223	9·488	884	29·732	9·597
825	28·723	9·379	855	29·240	9·491	885	29·749	9·601
826	28·740	9·383	856	29·257	9·495	886	29·766	9·605
827	28·758	9·386	857	29·275	9·499	887	29·783	9·608
828	28·775	9·390	858	29·292	9·502	888	29·799	9·612
829	28·792	9·394	859	29·309	9·506	889	29·816	9·615
830	28·810	9·398	860	29·326	9·510	890	29·833	9·619
831	28·827	9·402	861	29·343	9·513	891	29·850	9·623
832	28·844	9·405	862	29·360	9·517	892	29·866	9·626
833	28·862	9·409	863	29·377	9·521	893	29·883	9·630
834	28·879	9·413	864	29·394	9·524	894	29·900	9·633
835	28·896	9·417	865	29·411	9·528	895	29·917	9·637
836	28·914	9·420	866	29·428	9·532	896	29·933	9·641
837	28·931	9·424	867	29·445	9·535	897	29·950	9·645
838	28·948	9·428	868	29·462	9·539	898	29·966	9·648
839	28·965	9·432	869	29·479	9·543	899	29·983	9·651
840	28·983	9·435	870	29·496	9·546	900	30·0	9·655

SQUARE ROOTS AND CUBE ROOTS.—*Cont.*

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
901	30·017	9·658	936	30·594	9·782	971	31·161	9·902
902	30·033	9·662	937	30·610	9·785	972	31·177	9·906
903	30·050	9·666	938	30·627	9·789	973	31·193	9·909
904	30·067	9·669	939	30·643	9·792	974	31·209	9·913
905	30·083	9·673	940	30·659	9·796	975	31·225	9·916
906	30·100	9·676	941	30·676	9·799	976	31·241	9·919
907	30·116	9·680	942	30·692	9·803	977	31·257	9·923
908	30·133	9·683	943	30·708	9·806	978	31·273	9·926
909	30·150	9·687	944	30·725	9·810	979	31·289	9·929
910	30·166	9·691	945	30·741	9·813	980	31·305	9·933
911	30·183	9·694	946	30·757	9·817	981	31·321	9·936
912	30·199	9·698	947	30·773	9·820	982	31·337	9·940
913	30·216	9·701	948	30·790	9·824	983	31·353	9·943
914	30·232	9·705	949	30·806	9·827	984	31·369	9·946
915	30·249	9·708	950	30·822	9·830	985	31·385	9·950
916	30·265	9·712	951	30·838	9·834	986	31·401	9·953
917	30·282	9·715	952	30·854	9·837	987	31·417	9·956
918	30·299	9·719	953	30·871	9·841	988	31·432	9·960
919	30·315	9·722	954	30·887	9·844	989	31·448	9·963
920	30·331	9·726	955	30·903	9·848	990	31·464	9·967
921	30·348	9·729	956	30·919	9·851	991	31·480	9·970
922	30·364	9·733	957	30·935	9·855	992	31·496	9·973
923	30·381	9·736	958	30·952	9·858	993	31·512	9·977
924	30·397	9·740	959	30·968	9·861	994	31·528	9·980
925	30·414	9·743	960	30·984	9·865	995	31·544	9·983
926	30·430	9·747	961	31·0	9·868	996	31·559	9·987
927	30·447	9·750	962	31·016	9·872	997	31·575	9·990
928	30·463	9·754	963	31·032	9·875	998	31·591	9·993
929	30·479	9·757	964	31·048	9·879	999	31·607	9·997
930	30·496	9·761	965	31·064	9·882	1000	31·623	10·0
931	30·512	9·764	966	31·081	9·885			
932	30·529	9·768	967	31·097	9·889			
933	30·545	9·771	968	31·113	9·892			
934	30·561	9·775	969	31·129	9·896			
935	30·578	9·778	970	31·145	9·899			

935 | 30·578 | 9·778 | 970 | 31·145 | 9·890

SECTION II.

FIELD DEFENCES.

See PREFACE.

2nd Reserve

FIELD DEFENCES

SECTION II.

SECTION III.

MILITARY BRIDGES.

Bending Moments.

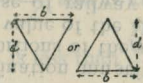
Table—Maximum Bending Moment.

Member.	How Loaded.	Value of M_{ff}.	Position of M_{ff}.
Cantilever	Concentrated load at end	WL	At point of fixing.
Ditto	Distributed load	$\frac{WL}{2} = \frac{wL^2}{2}$	Ditto.
Supported beam	Concentrated load at centre	$\frac{WL}{4}$	At centre.
Ditto	Distributed load	$\frac{WL}{8} = \frac{wL^2}{8}$	Ditto.

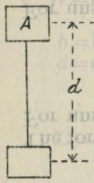
The length of the cantilever or beam is taken as L and the total load as W.

In the case of distributed loads $W = wL$, where w is the load per unit of length.

Values of Section Modulus, Etc.

Form of Section.		Section Modulus. $Z = \frac{I}{y}$.	Moment of Inertia. I.	Extreme Fibre Distance. y.
Solid rectangle.		$\frac{b\,d^2}{6}$	$\frac{b\,d^3}{12}$	$\frac{d}{2}$
Hollow rectangle.		$\frac{b\,d^3 - b_1 d_1^3}{6d}$	$\frac{b\,d^3 - b_1 d_1^3}{12}$	$\frac{d}{2}$
H section.		$\frac{b\,d^3 - (b - b_1)\,d_1^3}{6d}$	$\frac{b\,d^3 - (b - b_1)\,d_1^3}{12}$	$\frac{d}{2}$
Triangle.		$\frac{bd^2}{24}$	$\frac{bd^3}{36}$	$\frac{2d}{3}$
Rectangle with a diagonal horizontal.		$\frac{a^2c^2}{6\sqrt{a^2+c^2}}$	$\frac{a^3c^3}{6\,(a^2+c^2)}$	$\frac{ac}{\sqrt{a^2+c^2}}$
Rectangle with a diagonal vertical.		$\frac{a^5c+ac^5}{6\,(a^2+c^2)^{\frac{3}{2}}}$	$\frac{a^5c+ac^5}{12\,(a^2+c^2)}$	$\frac{\sqrt{a^2+c^2}}{2}$
Solid circular section.		·0982 D^3	·0491 D^4	$\frac{D}{2}$
Hollow circular section.		·0982 $\frac{D^4 - D_1^4}{D}$	·0491 $(D^4 - D_1^4)$	$\frac{D}{2}$
Semi-circular section.		·0238 D^3	·00686 D^4	·288 D

An approximation used in calculating girder bridges is :—



$$M_r = rAd.$$

When A = area of one boom,
d = depth between centres of booms.

Timber Columns and Struts.

Long and Short Columns.—It is not possible to draw a hard-and-fast line between long and short columns ; it depends to a great extent upon the material. As a rough rule the ratio of length to least dimension should not exceed 8 to 1 if the column is to be treated as a short one. In the case of a column of non-uniform section—a tapering spar, for example—the least dimension to be taken for purposes of calculation is that of its middle section, for it is at this section that the maximum stress intensity will occur.

Round and Fixed Ends.—The strength of a column also depends upon the way in which its ends are secured. If they are free to turn they are said to be " round," and if they are not able to rotate they are said to be " flat " or " fixed." A column with fixed ends is as strong as one of the same least dimension and half its length, and if one end is fixed, as strong as one two-thirds its length. Before any extra strength can be assumed on this account it is necessary to be sure that the fixing is very thorough, and that no rotation is possible in any direction if the cross dimensions of the section are about equal, or that no rotation is possible in the plane containing the least dimension if this is decidedly less than the other dimension of the cross-section.

Rough Rule.—A rough rule to allow for this diminution of strength, as the ratio of length to least dimension increases, is given below. In this rule the allowable safe stress becomes less as this ratio increases. If r is taken as the safe compression in lbs. per square inch—for example, on a short column in which there is no danger of buckling—L the length of the column and d the least

dimension, in the same units as L, then, the ends being considered round—

When L is not greater than	8 *d*,					safe stress is	*r*.
,, L is between	8 *d*	and	12 *d*	,,	,,	5/6 *r*.
,, L ,,	12 *d*	,,	24 *d*	,,	,,	1/2 *r*.
,, L ,,	24 *d*	,,	36 *d*	,,	,,	1/4 *r*.
,, L ,,	36 *d*	,,	48 *d*	,,	,,	1/6 *r*.

Rough Formulæ.

Formulæ for Calculating Size for Roadbearers, Transoms and Cantilevers.

Rough formulæ for calculating the sizes necessary for roadbearers and transoms, etc., are given below. The formulæ include a factor of $1\frac{1}{2}$ for live load, in addition to a factor of safety of 3; they also allow for a normal weight of superstructure.

For unselected rectangular beams supported at both ends :—

$$W = \frac{bd^2}{L} \times K \quad \text{.....(i.).}$$

For unselected round spars supported at both ends :—

$$W = \tfrac{6}{10} \times \frac{d^3}{L} \times K \quad \text{.....(ii.).}$$

The formulæ for strength of cantilevers are as follows :—
For unselected rectangular beams fixed at one end :—

$$W = \tfrac{1}{4} \times \frac{bd^2}{L} \times K \quad \text{.....(iii.).}$$

For unselected round spars fixed at one end :—

$$W = \tfrac{1}{4} \times \tfrac{6}{10} \times \frac{d^3}{L} \times K \quad \text{.....(iv.).}$$

In the above formulæ—

W = actual load on one beam in cwts. evenly distributed (without superstructure).

b = breadth of beam in inches.

d = depth of beam in inches.

L = length of beam in feet between points of support for (i.) and (ii.).
length of cantilever in feet from point of support for (iii.) and (iv.); or, if loaded at one point only (see below), length from point of support to position of load.

K = a variable quantity for different timbers.

For larch and cedar	K = 1
,, Baltic fir	K = $\frac{5}{4}$
,, American yellow pine	K = $\frac{6}{4}$
,, beech and English oak	K = $\frac{7}{4}$

In the case of round spars b and d are identical, and their strength is only about six-tenths that of square beams of the same depth.

To use these formulæ for a *concentrated* weight, such as a gun, the total weight on the gun wheels must be multiplied by two to convert it to the equivalent *distributed* weight, when it can be substituted for W. When, as in the case of a transom, the load is applied at several points, it can be taken as distributed.

With several baulks under a roadway, the two outer carry only half as much of any weight as the inner ones.

Rectangular beams should always be used on edge, in order to obtain the maximum of rigidity and strength. In calculating the sizes of beams by the formulæ in 1 and 2 above, if b and d are unknown, d should be considered equal to $2b$.

A tapering spar, when supported at both ends, and overloaded, will break in the centre.

The table below gives a few of the principal loads to be met with on road bridges :—

Traffic.		Load and Nature of Load.		
Infantry in single file ...	Crowded at a check but formation not lost.	140 lbs. or 1¼ cwts. per foot-run distributed live load.		
,, ,, file		280 ,, 2½ ,,	,, ,,	,,
,, ,, fours ...		560 ,, 5 ,,	,, ,,	,,
Cavalry in single file ...		200 ,, 1¾ ,,	,, ,,	,,
,, ,, half-sections ...		400 ,, 3½ ,,	,, ,,	,,
13-pr. Q.F. gun		2,570 ,, 23 ,,	maximum concentrated live load on 1 pair of wheels.	
18-pr. Q.F. gun		2,700 ,, 24 ,,	,, ,,	,,
4·5" howitzer		,, 26 ,,	,, ,,	,,
60-pr. B.L. gun		7,460 ,, 67 ,,	,, ,,	,,
Heavy steam lorry, front axle		80 ,,	concentrated live load.	Axles 14' apart.
,, ,, rear axle		160 ,,	,, ,,	Overall length 23'.

An examination of these loads shows that there are four principal guiding loads :—

(1). Infantry in single file.
(2). Infantry in file—greater than cavalry in single file.
(3). Infantry in fours—greater than cavalry in half sections, field guns and field howitzers.
(4). Heavy steam lorry—greater than any other road traffic.

Bridge calculations therefore generally have to deal with one or other of these loads.

Live loads are generally converted to equivalent dead loads by multiplying by 1½.

For mechanical transport, however, over short spans the factor is 2 For longer spans this may be reduced, as the weight of the girders, etc., will absorb a great deal of the vibration.

A table is given below of equivalent distributed live loads for a series of heavy steam lorries moving with 11 clear distance beween them :—

EQUIVALENT DISTRIBUTED LIVE LOAD.

Span in feet	5	10	15	20	25	30	35	40	45	50
Load in tons per foot-run...	3·20	1·60	1·07	·80	·64	·57	·52	·47	·44	·42
Span in feet	55	60	65	70	75	80	85	90	95	100
Load in tons per foot-run...	·40	·38	·37	·36	·37	·37	·37	·37	·37	·37

Ruling Dimensions.

Traffic.		Width of Roadway. Single Line of Traffic.		Headway.
Nature.	Formation.	Between Ribands or Wheel Guides.	Between Handrails.	
				Ft. In.
Infantry	Single file.	1½′ to 3′	2½′ to 4′	—
Infantry	File.	6′	8′	—
Cavalry	Single file.			9 0
Horsed military carriages...	Drawn over by hand.			9 0
Infantry	Fours.	Min. 8′ Normal 9′	10′	—
Cavalry	Half-sections.			9 0
Horsed military carriages...	Fully horsed.			9 0
Motor omnibuses	—	8′ 6″	12′	14 6
Large traction engines ..	—			14 6
Other mechanical transport	—			12 0
Camels	Loaded.	Normal 9′	10′	11 0
Elephants	Loaded.	Normal 9′	12′	15 0

A width of 10′ between ribands will allow mounted orderlies to pass a column.

Handrails should be 3′ above the roadway.

Graphical Determination of Stresses.

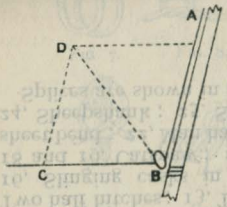


Fig. 1.

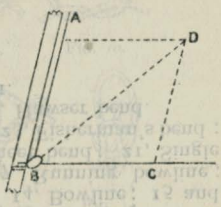


Fig. 2

Fig. 3.

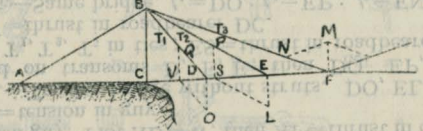


Fig. 4.

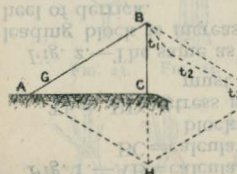


Fig. 5.

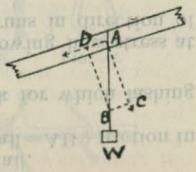


Fig 6.

Fig. 1.—AB=calculated tension in fall.
BC=calculated tension in fall=AB+friction in block B say $\frac{1}{10}$.
Then BD=stress in leading block for which lashing must be calculated.

Fig. 2.—The same as *Fig.* 1, and showing how stress at leading block is increased when fall runs in direction of heel of derrick.

Fig. 3.—AB represents a derrick lifting weight W, AC being back guy. Plot AD=W, then AF=thrust in derrick, and AE=tension in guy.

Fig. 4.—Tension bridge without struts. DO, EL, FM=half load on transoms D, E, F; then DQ, EP, FN=tensions T_1, T_2, T_3 in ties; ES=thrust in roadbearer ED; ES+DV=thrust in roadbearer DC.

Fig. 5.—Same bridge. t_1=DQ; t_2=EP; t_3=FN; then BR=total pull at B Make angle GBC=RBC; and thrust will be down frame BC; and BH=thrust in each leg; and BA=tension in each back guy.

Fig. 6.—AB=oblique stress W, which can be resolved into the transverse stress AC, and stress AD in direction of length of beam.

Knots, Lashings, etc.

These are best described by the accompanying figures :—

Fig. 7, Clove hitch; 8, Draw knot; 9, Ditto for small cordage; 10, Reef knot; 11, Clove hitch round a post; 12, Two half hitches; 13, Timber hitch; 14, Bowline; 15 and 16, Slinging casks in bowline; 17, Running bowline; 18 and 19, Catspaw; 20, Double sheet bend; 21, Single sheet bend; 22, Man harness hitch; 23, Fisherman's bend; 24, Sheepshank; 25, Slip knot; 26, Hawser bend.

Splices are shown in *Figs.* 27 to 31.

FIG 7. FIG. 8. FIG. 9. FIG. 10.

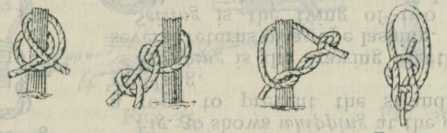


FIG. 11. FIG. 12. FIG. 13. FIG. 14.

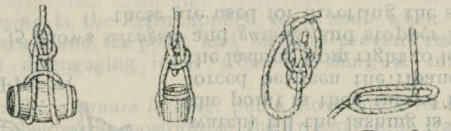


FIG. 15. FIG. 16. FIG. 17. FIG. 18.

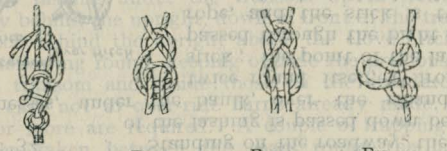


FIG. 19. FIG. 20. FIG. 21. FIG. 22.

FIG. 23. FIG. 24. FIG. 25. FIG. 26. FIG. 27.

FIG. 28. FIG. 29. FIG. 30. FIG. 31.

The Blackwall hitch (*Fig.* 32) is used for fastening the end of a fall to the hook of a block. It only holds while the strain is on. A good method of fastening the fall to the ring of a block is with a single sheet bend as shown.

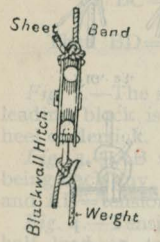


FIG. 32.

The lever hitch (*Fig.* 33) is useful for fastening the rounds of a rope ladder, for parallel bars on a drag rope, etc.

Rack lashings (*Fig.* 34) are in 8′ lengths of 1½″ rope, with a short stick at one end.

Standing on the roadway, the point of the lashing is passed down between two chesses, under the baulk, over the riband and twice round itself, 1′ from the stick; the point of the latter is passed through the bight of the rope, and the stick is twisted round (against the hands of a watch) till the lashing is tight; the point is then turned in and forced between the riband and the lashing from right to left.

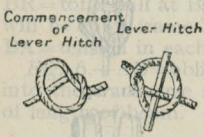


FIG. 33.

Fig. 35 shows *selvagees* and *gaskets*, and stopper hitch; these are used for diverting the strains on ropes.

FIG. 34.

Fig. 36 shows *whipping* at the end of a rope to prevent the strands unravelling.

Frapping is the drawing together of several returns of a rope lashing.

Seizing is the tying of two ropes together with spun yarn. Take the centre of the yarn and tie a clove hitch at that point on one of the ropes, then take each part round and round the two ropes in opposite directions, leaving one end long enough to take two frapping turns between the ropes; the ends are then connected by a reef knot.

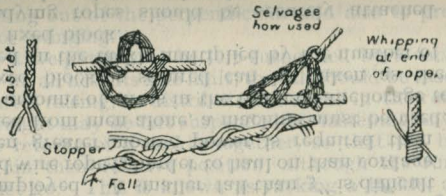


FIG. 35. FIG. 36.

Mousing is the term applied to a hook when bound with yarn round the point and back, to prevent its clearing or disengaging itself from anything it may be hooked to.

To make a *square lashing*, put a clove hitch round the upright below the position of the crosspiece or transom, take the lashing under the transom up in front horizontally behind the upright, down in front of the transom, and back behind the upright above the clove hitch, and so on, following round, keeping outside the previous turns on the transom and inside those on the standard, and taking care not to over-ride turns already made. Four turns or more are required. A couple of frapping turns are then taken between the spars round the lashing, binding the whole firmly together, and the lashing is finished off with a clove hitch either round the lashing or one of the spars.

Strength cordage square lashing $= \frac{4}{5} \times$ number of returns from spar to spar $\times$ strength of cordage.

Strength wire square lashing $= \frac{3}{5} \times$ number of returns from spar to spar $\times$ strength of wire, *e.g.*, the strength of a 2″ hemp rope square lashing with four complete turns $= \frac{4}{5} \times 16 \times 2^2$ cwt. $= 51$ cwt.

BLOCKS AND TACKLES.

Various descriptions of blocks and tackle are shown in *Fig.* 37. The theoretical weight any system of blocks

will lift is found by multiplying the power by the number of ropes at the movable block, including the standing end if fixed to it. There is, however, an excess of power required to overcome friction. This may vary from $\frac{1}{8}$ to $\frac{1}{10}$ with tackles in excellent condition; for average tackles with falls of tarred rope it may be taken as $\frac{1}{6}$; for tackles in bad condition $\frac{1}{5}$ or more.

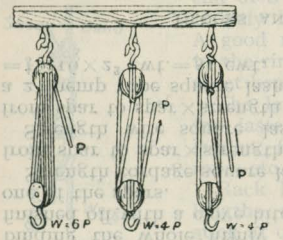


FIG. 37

Where P = power actually required to lift the weight,
W = weight to be lifted,
G = theoretical advantage or number of returns at movable block,
f = coefficient of friction varying from $\frac{1}{10}$ to $\frac{1}{5}$,
n = total number of sheaves,

$$P = \frac{W}{G}(1 + fn).$$

It has been found by experiment that squads of men, up to 60 in number, can exert about half their weight on a horizontal fall. Two or three men, pulling upwards or downwards, can each pull more than this; but more cannot work together. With men of average weight, their pull can be taken as 80 lbs., or $\frac{3}{4}$ cwt., according to the unit employed. A smaller fall than 3″ is difficult to haul on, and wire rope is harder to haul on than cordage.

When greater motive power is required than can be obtained from men alone, a machine must be used.

The amount of stress in the beam or anchorage to which the fixed block is secured can be taken as the power required on the tackle multiplied by the number of returns at the fixed block.

Steadying ropes should be securely attached to the weight and used to regulate its position gently, especially

when lifting out of the perpendicular and also to prevent surging or swinging.

When a weight has to be left suspended by a tackle if working at all near its safe limit, the fall should be eased off a little after raising, to distribute the stress in the returns.

The weight may be left suspended by fastening any two opposite returns of a tackle together, so that the blocks may retain their relative position, although the running end be let go. This is known as racking a tackle, and a rack-lashing may be used to stopper the returns of a tackle in this way.

Wire rope should not be worked round a sheave or barrel of less diameter than six times the circumference of the rope.

Capstans are very useful in connection with tackles for raising heavy weights.

A substitute for a capstan may be formed out of a stout wheel, laid upon its face on the ground with an axle put into it, fitted with a round piece of timber as the barrel of a capstan, and bars to work it lashed across the head (*Fig.* 38).

IMPROVISED CAPSTAN.

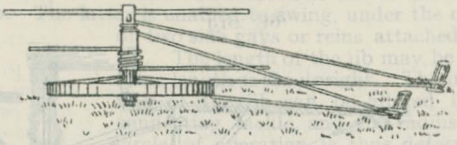


FIG. 38.

To lash a block to a spar, lay the back of the hook against the spar, make a clove hitch on the spar above the hook, take several turns round the hook and spar, and then several more round the spar below the hook and secure.

DERRICKS AND SHEERS.

A *derrick* is a single spar set up with four guys, secured with clove hitches, and one or more blocks are lashed to the tip. Slope of guys, $\frac{1}{2}$. Maximum inclination of spar, $\frac{3}{4}$.

A *swinging derrick* consists of a standing derrick with a swinging arm attached to it near its foot. The tip of this swinging arm is connected to the upright spar by a connecting tackle, and the main or lifting tackle is attached to the tip of the swinging arm or jib (*Fig.* 39). The upright spar is practically the same as a standing derrick,

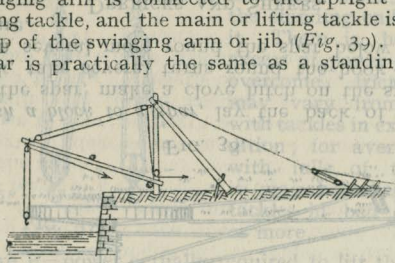


FIG. 39.

with the exception that as it will frequently be erected at the edge of a wharf or other place where it is not convenient to use a fore guy, a strut or struts must be used instead. A good method is to use two struts, each about half as long again as the upright spar, lashing the three together as in a gyn and then to erect it so that the standing derrick is vertical and the two struts are at right-angles in plan, and situated symmetrically with respect to the edge of the wharf. Two guys can also be used, one over each strut in plan, but secured to holdfasts at the customary distance; or three guys can be used, one a back guy and the other two side guys, but set back about 20° from the edge of the wharf, to allow room for the loads to be landed. It is important that these guys should not stretch too much, so that the upright spar may remain vertical. It is therefore better to make them of wire rope, and in any case a tackle should be included in them to take up any slack. The stress in these guys is much greater than that in guys for a standing derrick to deal with the same weight.

The jib is most conveniently formed of two spars, lashed together at their tip, and separated at their butts to a distance about equal to the diameter of the upright spar.

They are lashed about 1′ or 18″ from their butts to a stout crosspiece, and the end thus formed encircles the butt of the upright (*Fig.* 40). The jib is supported by a

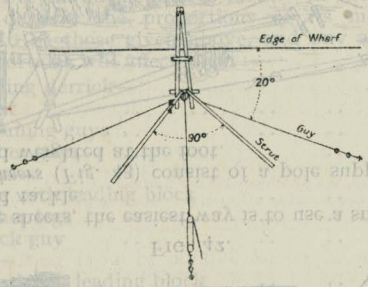


FIG. 40.

length of chain, secured at its centre by a clove hitch round the upright and prevented from descending by a collar of rope, and each end secured to one of the arms of the jib. The latter is enabled to swing, under the control of two side guys or reins attached to its tip. The length of the jib may be of the same length as the upright. The inclination of the jib can be altered by the connecting tackle, and the radius of its circle of operation is thus determined. The weight can be lifted or lowered by the main tackle and the jib swung by the reins. The jib can only be swung right over the edge of the wharf on that side of the upright on which are the leading blocks of the main and connecting tackles. If it is necessary to swing both ways, duplicate leading blocks for the falls of these tackles must be provided. If one spar only is available for the jib it should be fastened to the upright spar, as shown on *Fig.* 41.

FIG. 41.

To make a *sheers*, lay two spars alongside of each other, with their butts together, on the ground. A clove hitch is then made on one spar, and the lashing taken loosely 6 or 8 times round both. Two or three frapping turns are taken between the spars, and finished with a clove hitch above the round turns on the other spar. The butts of the spars are then opened out, and a sling passed over the fork, to which a block is hooked or lashed. Fore and back guys are then fastened, so as to draw the heads together when the strain is on (*Fig.* 42). Foot ropes are then secured to the feet and to pickets, and the sheers are ready for hoisting. The distance apart of sheer legs should not be more than one-third their height to lashing. Slope of guys, $\frac{1}{2}$. Maximum inclination of sheers, $\frac{3}{1}$.

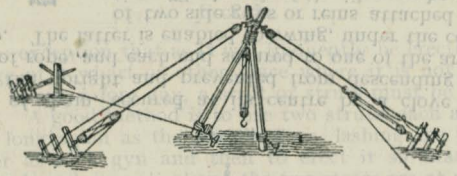


FIG. 42.

To raise sheers, the easiest way is to use a small derrick, blocks and tackle.

Lever sheers (*Fig.* 43) consist of a pole supported on a crutch and weighted at the foot.

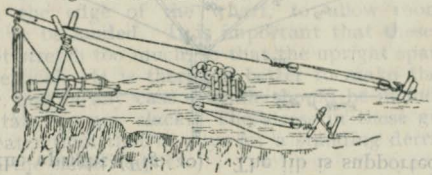


FIG. 43.

The following table gives the stresses in terms of the weight lifted by the main tackle in the various members

under the worst conditions obtaining in practice. These figures do not include an allowance to convert the live load into its equivalent dead load, but they do allow for the weight of the tackle and so forth. In the case of the swinging derrick, the proportions of its members are assumed to be those given above, and any alteration in these proportions will affect them :—

Standing derrick—	
Spar	1·5 W.
Running guys	·5 W.
Other guys	·3 W.
Sheers—	
Leg with leading block	·9 W.
Other legs	·7 W.
Back guy	·6 W.
Gyn—	
Spar with leading block	·6 W.
Other spars	·4 W.
Swinging derrick—	
Upright spar } same length	2·0 W.
Swinging arm } same length	1·3 W.
Struts	1·0 W.
Connecting tackle	1·7 W.
Guys	1·5 W.

Holdfasts and Anchorages.

5 pickets, 3″ diameter, driven 3′ into the ground, should safely stand pulls as under in good ground :—

Single picket	7 cwts.
1—1 picket holdfast	14 ,,
2—1 ,, ,,	1 ton.
3—2—1 ,, ,,	2 tons.

Unless the ground is very soft the strength of the pickets will generally be the ruling factor. For pulls greater than 2 tons a log may be used in conjunction with a series of 1—1 picket holdfasts (*Fig.* 45). This should safely stand 12 cwts. per holdfast. There should be the same number of holdfasts on each side of the cable, and they should be symmetrically arranged with respect to the cable. Care

must be taken that the log bears equally against all the pickets in the front row. The log should rest on the ground and sufficient soil be removed to allow the cable to be passed round it.

3, 2, 1, HOLDFAST.

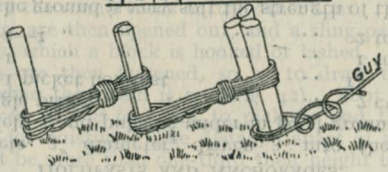


FIG. 44.

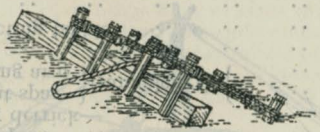


FIG. 45.

The following table of holding power of loamy earth will be useful :—

Mean Depth of Face of Anchorage below Surface.	Inclination of the Force drawing the Anchorage (in a direction perpendicular to its face), and Corresponding Safe Resistance in lbs. per square foot of Anchor-Face.				
	Vertical.	¼	½	⅜	¼
1′	70	110	150	160	175
1′ 6″	150	250	320	360	390
2′	290	410	580	650	700
3′	600	950	1,300	1,450	1,500
4′	1,050	1,750	2,200	2,600	2,700
5′	1,700	2,800	3,600	4,000	4,100
6′	2,400	3,800	5,100	5,800	6,000
7′	3,200	5,100	7,000	8,000	8,400

Assumptions.—Weight of earth, 90lbs. per cubic foot; angle of repose, 30°; 5′ standing height when freshly cut; factor of safety, 3.

With wet soil the holding power is lessened. For hard, compact gravel, rammed, take ·9; for river clay, rammed, take ·5; and river sand, not rammed, take ·5 of the above results.

The holding power with round and half-round beams is about the same as a square beam with a side equal to the diameter.

For an anchorage several feet deep take the sum of the resistance given above, *e.g.*, for one 8′ deep take 5′+3′. The required resistance will not be *less*, though it may be more.

Various types of anchorages are shown in *Figs.* 46 to 50.

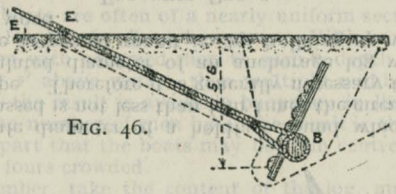


FIG. 46.

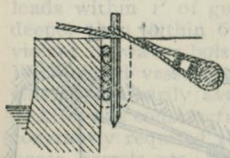


FIG. 47.

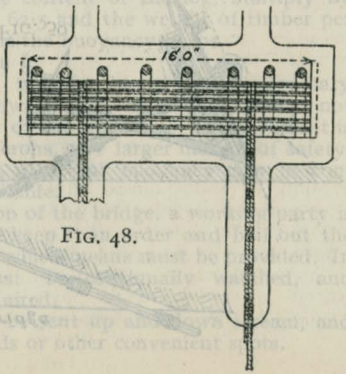


FIG. 48.

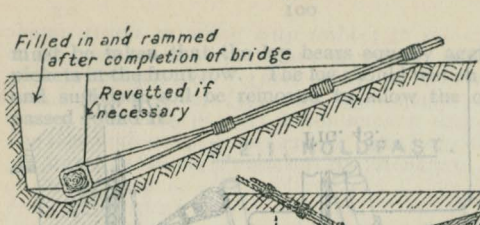


FIG. 49.

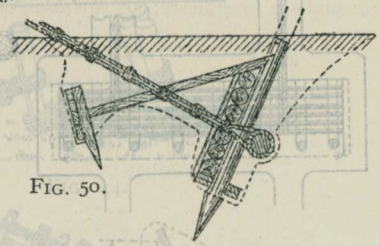


FIG. 50.

The safe diameter of a holdfast round which a *wire rope* is passed is not less than four times the circumference of the rope. Therefore it is generally necessary to enlarge the calculated diameter of an anchorage log where the wire rope is passed round it, by building up with short pieces of wood.

FLOATING BRIDGES.

General Principles.

Floating bridges consist of a continuous roadway supported on piers of pontoons, boats, casks, etc. Each of these piers must have sufficient buoyancy to support the heaviest load that can come over it. The buoyancy of the various piers must be ascertained, and only part of the actual buoyancy can be taken as available, the margin allowed being greater in bridges over rough water or in those intended to remain in use for a long time. In calculating for *buoyancy* no allowance need be made for loads being live or moving instead of dead or stationary; but in calculating for *strength of roadbearers, etc.*, of course this allowance must be made.

For the sake of stability *the piers should be twice as long* as the roadway is wide, unless the buoyancy is much in excess of that required.

The *clear waterway* between two piers of a bridge constructed in a stream of over 4 miles an hour should not be less than the width of one pier.

Casks bear *grounding* very well. A pier of five 100-gall. casks has been tested when grounded on gravel bottom with a load of 12 tons with no apparent damage. Pontoons should not be allowed to ground under a load if it can be avoided, and then only on a smooth surface. Boats, unless flat-bottomed, should not be allowed to ground with a weight on them.

Buoyancy of Boats.

Large boats are often of a nearly uniform section ; this section × length × 62·5lbs. = buoyancy. With small boats, load them with unarmed men to such a depth as is safe (gunwale 1′ above water), then multiply number of men by 160 ; the result is available buoyancy in lbs. If you divide the number of men by 4, the result is the number of feet apart that the boats may be from centre to centre to carry fours crowded.

For timber, take the content of the log, multiply by the difference between 62·5 and the weight of timber per cubic foot ; the result is the buoyancy in lbs.

For Casks see Section I.

Open boats should not be immersed by ordinary loads within 1′ of gunwale, and, on an emergency, not deeper than within 6″ of the gunwale. If the current is violent, or waves boisterous, give larger margin of safety. With closed vessels, $\frac{9}{10}$ of actual buoyancy may be considered ordinarily available.

After the construction of the bridge, a working party is constantly required to keep it in order and bail out the boats, barrels, etc., for which means must be provided. In floods the cables must be continually watched, and slacked off, etc., as required.

Guard boats should be sent up and down stream, and guards posted on islands or other convenient spots.

To prevent damage to the bridge from floating objects, booms either floating or fixed, or both, may be placed about 1,000 yards from the bridge. A strong chain or hawser, stretched across a stream and buoyed, if necessary, will check floating objects, or fire some kinds of torpedoes; but a boom formed of large logs chained together is a better obstacle. These floating booms should be oblique to the stream (20° with the banks); they require stream anchors, and their ends should be secured to land anchorages. They must have play to rise and fall with the water.

Fixed obstacles may be made of groups of piles, with their heads tied together by rails spiked to them; groups of these may be used with floating booms between them.

Torpedoes, etc., have been intercepted by stretching strong nets (weighted and buoyed) across the stream, or else wooden frames, resting against piles, and covered with wire netting. A light rope or wire stretched across a river can be made to pull a bell or fire a charge, so as to give an alarm.

Anchors.—To ensure holding, the length of cables should be 10 times depth of stream, but not less than 30 yards. When the length is less than three times the depth the anchors seldom hold. *Fig.* 51 shows the method of fastening a buoy-line to an anchor.

FIG. 51.

In the absence of anchors, and in streams not more than 100 yards wide, a hawser can be stretched across buoyed with floats, and its ends secured to land-ties on each bank at a distance up stream equalling one fourth of a span. Cables are to be secured to it.

It is sometimes advisable in floating bridges, where the anchorage in the bed is insecure, to fasten all the piers (whether of pontoons, boats, or casks, etc.) to the cable, which becomes a sort of horizontal suspension cable, and should be securely anchored to either bank. This method is much used in India.

Makeshift anchors may be formed of pickaxes ; of casks filled with stones ; of rails ; of wicker baskets ; harrows ; wheels, etc., etc. Cables may be secured to piles.

In floating bridges, generally the most buoyant piers are placed at the shore ends, and those offering least resistance to the current in the middle.

Boats are used either singly or in pairs to form the piers of a floating bridge.

The baulks rest on a central *saddle beam*, which should be fixed longitudinally in the centre of each boat, its upper surface being raised a little above the gunwales, and its length depending on the width of roadway required. In large boats with strong sides this saddle may be fastened on beams laid across the gunwales, but in boats of slight build it should be supported on the kelson. The baulks are laid from saddle to saddle, and secured by pins or lashings.

Another way to strengthen weak boats is to support the saddle on cross-pieces with cleats, which grip the gunwales, and prevent them from being thrust out by a load.

Baulks may also be laid on a sort of midship deck, their ends abutting against a middle piece of timber, thus preventing two boats from coming nearer to each other.

When barges or large lighters of a capacity of 20 tons and upwards are available, and the timber for baulks is short, gunwale pieces of wood, with cleats to receive the baulks, may be laid on each gunnel, and the baulks laid across from the outside gunwale of one boat to the nearest gunwale of the next, other baulks being laid across from gunwale to gunwale of each boat.

The arrangement of *bridge ends in tidal rivers* is sometimes troublesome. Combination of trestles and floating piers will generally meet the case, the trestles being arranged at such a height as to take the roadway at low water and the floating piers at high water. Sometimes blocks and tackle at the trestle heads may be advantageously used for raising and lowering the roadway.

Pontoon Bridges.

There are many different varieties and patterns of pontoons.

It is, of course, very desirable that all troops equipped with them should be carefully drilled in the rapid formation of bridges, yet, as such drill is not an absolute necessity, it is not given here.

The method of forming bridges with pontoons, casks and boats is practically the same for every pattern. There are three ways: (*a*), *forming up* or connecting each pier in succession with the head of the bridge; (*b*), by *rafts* made up in any convenient place, rowed into position, and simultaneously placed; (*c*), by *swinging* the bridge entirely from one bank across the stream.

Timber-Raft Bridges.

Raft bridges are suitable in currents not exceeding 2 to 3 miles an hour; they need strong anchorages. The best woods to be used are the lightest. The size of the trees may vary from 25′ to 45′ in length, and from 30″ to 72″ in girth; if formed of smaller size than this they would be deficient in buoyancy and stability. If of greater size, moving the logs is difficult. The ends of the logs may be tarred to check absorption of water, but even with this precaution a loss of one-sixth buoyancy will often occur. The rafts are most conveniently put together in the water.

The logs for each raft are laid with large and small ends alternately. The upstream end may be made convex so as to offer less resistance to the current. The logs are secured by baulks spiked across, and a saddle is spiked in the centre longitudinally for the roadbearers. Fir baulks at the ends may often be required.

When additional buoyancy is required, more tiers of logs, laid at right angles, may be fixed.

Cask bridges are formed in a variety of ways. Generally, if timber is available, a framing secured round the casks in each pier is most convenient. *Fig.* 52 shows the method of securing casks with ropes to form a pier. The bungs

must be uppermost, or in such a position that any water which finds its way in may be pumped out through the bung-hole.

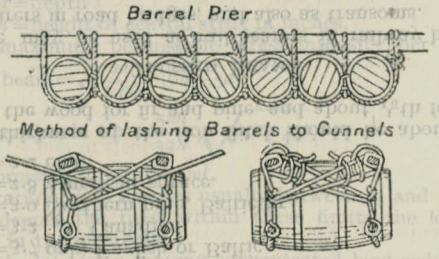


FIG. 52.

In forming a barrel-pier bridge, the baulks are lashed across the ends of the gunnels; these keep the piers in position, and afterwards the baulks need only be laid.

Bridges may also be formed from rafts of inflated skins, and of the vessels (*dubbas*) used in the Indian commissariat for *ghi*. The mouths should be uppermost, and a light framing of timber should be all round.

Flying Bridges.

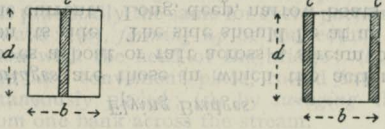
Flying bridges are those in which the action of the current moves a boat or raft across a stream by acting obliquely on its side. The side should be at an angle of 55° with the current. Long, deep, narrow boats are best, or a raft of two long boats.

The weight of the boat should be considerable compared with the cable. A velocity of at least 2 miles an hour is needed, and straight reaches are best. There are three ways of working:—(1). By a suspension cable. (2). By an anchorage and swinging cables. (3). By a warp. (1) is much used in India. The cable should be of wire, pulled as taut as possible over pillars set well back from the banks. (2) should have a length of cable 1½ to 2 times the breadth of the river; it should have intermediate points

of support. If the bridges hang as they near the banks a line from the pier may be buoyed in their track to help to pull them in.

Flitched Beams.

Wooden beams can be greatly strengthened by means of flitch plates of wrought iron or steel placed as shown below :—



b = breadth in inches.
d = depth in inches.
t = thickness of flitch in inches.
L = span in feet.
W = *Breaking weight* in cwts. in the centre.

$$W = \frac{d^2}{L}(Cb + 30t)$$

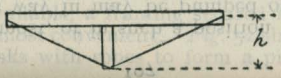
C = 4·0 teak.
= 3·7 oak, English or Baltic.
= 3·2 ,, Canadian.
= 3·0 Northern pine, Baltic fir.
= 2·8 American spruce.
= 2·2 elm.

The thickness of the iron flitch should be about $\frac{1}{12}$th that of the wood for fir and pine, and about $\frac{1}{10}$th for oak.

Trussed Beams.

These may be used as rail-bearers in railway bridges, roadbearers in road bridges, and also as transoms.

King truss :—



Let w = load per inch-run.
l = length of beam in inches.
b = breadth ,, ,,
d = depth ,, ,,
h = height of central strut in inches.

The maximum permissible stress intensity per square inch in beam $= \frac{1}{3^{\frac{1}{2}}} \frac{wl^2}{bd^2h} \quad (6h+5d)$.

The tension in ties $= \frac{5wl}{32h} \sqrt{l^2+4h^2}$.

Compression in strut $= \frac{5}{8}wl$.

The ratio of h to l varies usually between $\frac{1}{10}$ and $\frac{1}{5}$.

The deeper the truss within these limits the less the stresses in the members.

To calculate for a moving concentrated load reduce the concentrated load to its equivalent distributed load and apply the above formulæ.

Queen truss :—

Let W = a concentrated load.

The maximum permissible stress intensity per square inch in beam $= \frac{Wl}{6hbd^2} \quad (2h+d)$.

Tension in inclined ties $= \frac{W}{6h} \sqrt{l^2+9h^2}$

Tension in horizontal tie $= \frac{Wl}{6h}$, which is less than in the inclined ties, and need not usually be calculated.

Compression in strut $= \frac{W}{2}$.

For a distributed load :—

The maximum permissible stress intensity per square inch in beam $= \frac{wl^2}{90hbd^2} \quad (11d+6h)$.

Tension in inclined ties $= \frac{11wl}{90h}\sqrt{l^2+9h^2}$.

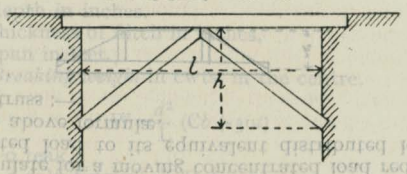
Compression in struts $= \frac{1}{8}\frac{1}{0}wl$.

With concentrated loads moving across the span reduce them to their equivalent distributed loads and calculate the beam. Then examine by means of the formula for W to see that too great a concentrated load is not being brought on the beam. If so, increase the equivalent distributed load and calculate again.

The ratio of h to l varies usually between $\frac{1}{6}\frac{1}{0}$ and $\frac{1}{8}$.

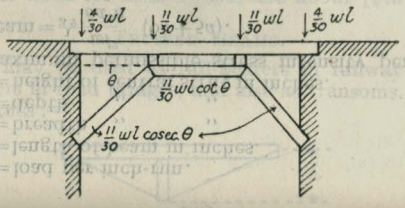
Camber.—Care should be taken not to provide camber by taking up on the tie-rods, as this will cause additional stresses in the truss.

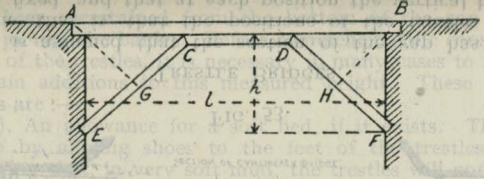
Strutted Beams.



Maximum permissible stress intensity per square inch in beam $= \frac{1}{3}\frac{1}{2}\frac{wl^2}{bd^2h}(6h+5d)$.

Compression in struts $= \frac{5wl}{32h}\sqrt{l^2+4h^2}$.





Maximum permissible stress intensity per square inch in CD $= \frac{wl^2}{9bd^2h}(h+d)$.

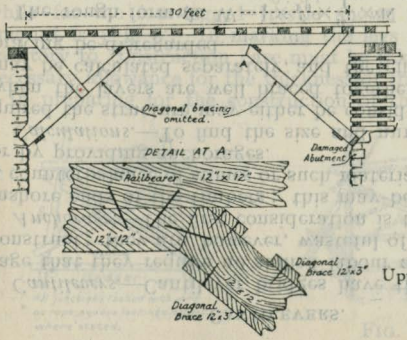
Compression in CE and DF $= \frac{wl}{9h}\sqrt{l^2+9h^2}$.

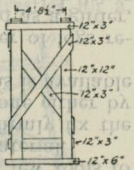
Maximum permissible stress intensity per square inch in AB $= \frac{wl^2}{12bd^2}$.

Diagonal pieces AG and BH are sometimes given. Their only object is to reduce the length of the struts EC, DF.

Strutted Railway Bridge.

Side Elevation.





Upper Side of Inclined Frame.

Cantilevers.

Cantilevers.—Cantilever bridges have the great advantage that they require no skilled labour and few tools to construct; they are, however, wasteful of material.

Anchorage.—The first consideration is to firmly fix the inshore ends of the timbers; this may be done either by a counterbalance of stones or such material as is available or by providing anchorages.

Calculations.—To find the size and number of logs required the structure may either be considered as a girder, when the layers are well braced together, or each layer may be calculated separately, and the effect of the cross-bracing be disregarded.

The rough formula $W=\frac{1}{4}\times\frac{6}{10}\times\frac{d^3}{L}\times K$ may be used as follows :—

Suppose w = the weight per foot-run, live load, in cwts., and b, c, d are the lengths of the cantilevers in each layer (*Fig.* 53); then for the

top layer $W=w\times(a+b)$ and $L=b$,
middle layer $W=w\times(a+b+c)$ and $L=c$,
bottom layer $W=w\times(a+b+c+d)$ and $L=d$.

For the anchorage, if W_e = the weight of earth, and W_r = the weight of the rails,

$$\text{then}\left(W_r+\frac{W_e}{2}\right)f=w\times(a\times b+c+d)\times\frac{b+c+d}{2}.$$

Fig. 53.

Trestle Bridges.

It is assumed that the section of the gap has been taken—that is, that the positions of the trestles have been fixed, and that at each position the vertical height

has been ascertained from the bottom of the gap to a line joining the banks. Before commencing the construction of the trestles, it is necessary in many cases to make certain additions to this measured height. These additions are :—

(1). An allowance for a soft bed, if it exists. This is done by affixing shoes to the feet of the trestles and allowing that, in very soft mud, the trestles will not sink more than about 12″. Or a horizontal member may form part of the trestle and be placed at or near the bottom of the legs. This increases the bearing surface on the soft bed, and in ordinary cases the trestle should not sink further than the middle of this member, which is termed a ledger. (On rocky ground, on the contrary, if there is a ledger it should not be placed near the bottom of the legs).

(2). *Camber.*—The amount to be allowed for each trestle will depend upon its position in bridge with reference to the ends of the bridge.

(3). If the legs of the trestle are not vertical, but are splayed outwards towards the feet, an allowance must be made for this fact in measuring the length along the leg from the butt to the transom. This allowance will depend upon the angle of the legs, and can be readily calculated. For the trestle shown on *Fig.* 54 it amounts to 1″ in 6′, while for the four-legged trestle shown in *Fig.* 55 the amount is 3″ in 6′. In marking the legs of a trestle preparatory to construction care must be taken to make the necessary allowance for the thickness of the roadway.

In preparing for the construction of the trestles for a

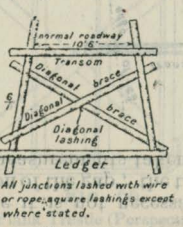


FIG. 54.

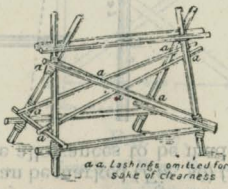


FIG. 55.

bridge it is not necessary to lay out on the ground th section of the gap ; the timbers can be marked (*Fig.* 56) fro the measurements taken and the allowances to be made.

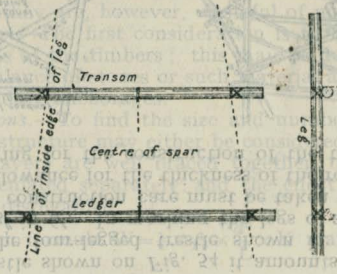


FIG. 56.

Framed Trestles.

The variety of trestles that may be made is very grea and the exact pattern to be chosen in any case will depen upon the timber and fastenings available. The best ar those which are framed together, with the transom restin on the head of the legs. Examples are shown on *Figs.* 5 to 68, which also show other methods of fastening th transom to the legs. Most of these require some form o iron fastening or wooden dowels. The iron fastenings mos commonly employed are dogs, drift-bolts, bolts and nut spikes, nails, fishplates, and hoop iron. The size of th timbers to be used will depend upon the loads to be carried.

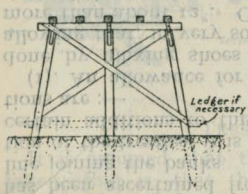


FIG. 57.

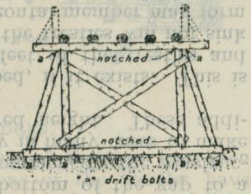


FIG. 58.

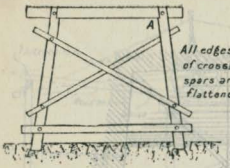


FIG. 59.
Spar Trestle with Dowels.

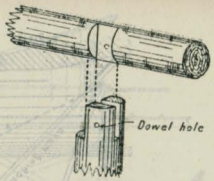


FIG. 60.
Detail at "A."

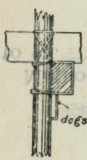


FIG. 61.

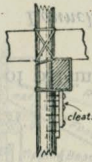


FIG. 62.

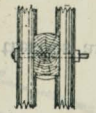


FIG. 63.

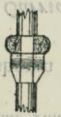


FIG. 64.

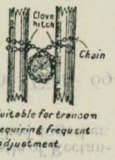


FIG. 65.

Other Methods of Fastening Transoms.

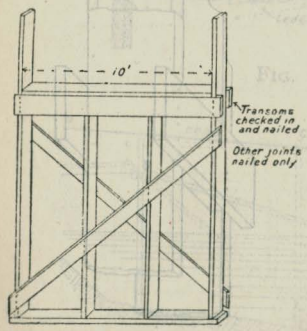


FIG. 66.
Plank Trestle (Perspective).

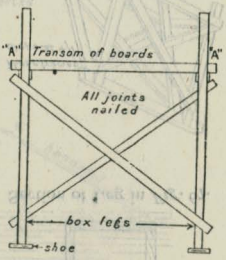
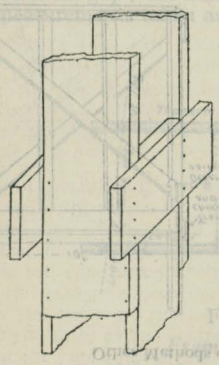


FIG. 67.
Trestle of Floor Boards
7"×1".



Detail at "A" (*Fig.* 67).

Section of Leg in *Fig.* 67.

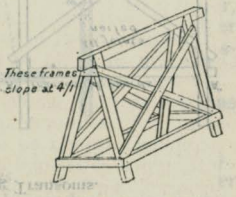


FIG. 68.

Four-legged Trestle of Rectangular Timber spiked together.

Methods of placing trestles are shown in the *Figs.* 69 to 77.

Launching Trestle by Carriage.

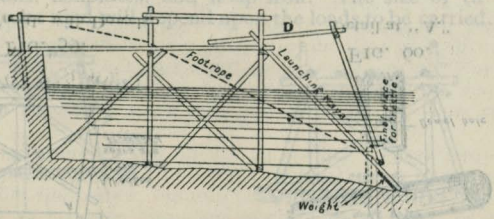


FIG. 69.

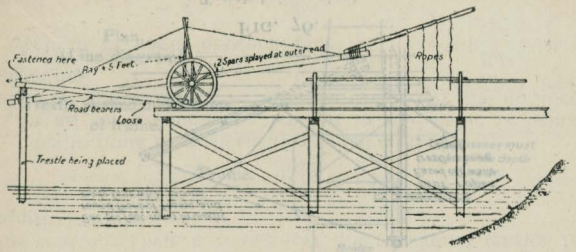


FIG. 70.

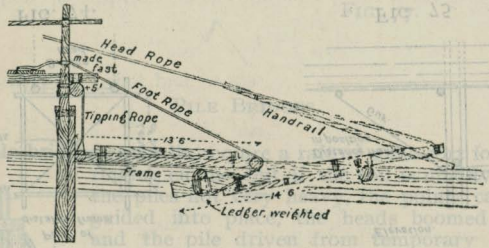


FIG. 71.

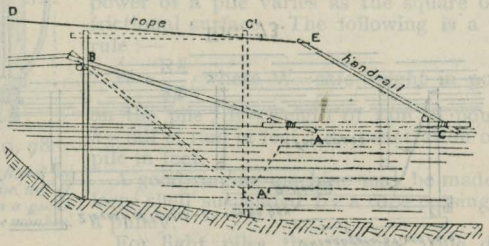


FIG. 72.

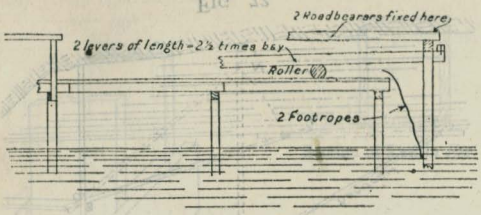


FIG. 73.

Raising Heavy Trestle by Distance Frame

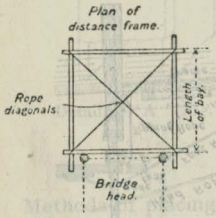


FIG. 74.

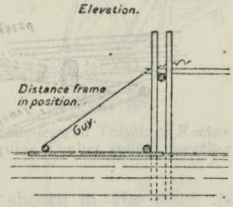


FIG. 75.

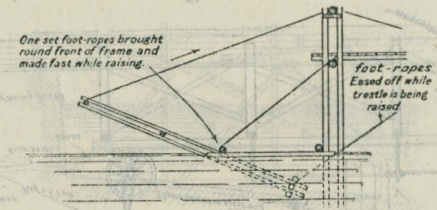

One set foot-ropes brought round front of frame and made fast while raising.
foot-ropes Eased off while trestle is being raised

FIG. 76.

Trestle being raised.

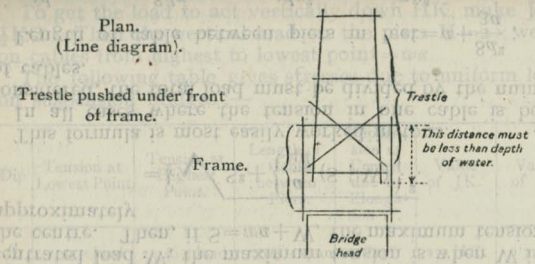


FIG. 77.

PILE BRIDGES.

Pile bridges generally require a raft of some sort for the ringing engine, but if the soil is muddy and the piles not very heavy, the points can be guided into place, the heads boomed out, and the pile driven from temporary platforms.

It is useful to remember that the sustaining power of a pile varies as the square of the frictional surface. The following is a good rule :—

$W = \frac{Rh}{8d}$, where W = safe weight in pounds on the pile ; R = weight of ram in pounds ; h = fall of ram in feet ; d = penetration of the pile in feet.

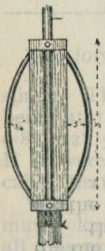


FIG. 78.

Pipe fixed in hole in top of pile as a guide for the monkey.

A good ringing machine may be made of a large shell suspended by a rope passing over a pulley.

For light piles the "Swiss" pile driver shown is very useful (*Fig.* 78).

Suspension Bridges.

Let (*Fig.* 79)

a = total span in feet.

d = total dip in feet.

w = load in lbs. per foot-run of bridge.

θ = the angle made with the horizon by a tangent to the curve at the highest point.

ϕ = the angle made by a tangent at any point P distant x feet from the lowest point and y feet above it.

Fig. 79.

Then tension O in lbs.

$$= \frac{wa^2}{8d}.$$

Tension at either pier in lbs.

$$= \frac{wa}{2}\sqrt{1+\left(\frac{a}{4d}\right)^2}.$$

When, in addition to the uniform load, there is a concentrated load W, the maximum tension is when W is at the centre. Then, if $S = wa + W$, the maximum tension is approximately

$$= \tfrac{1}{2}\sqrt{S^2+\left\{\frac{a}{4d}(S+W)\right\}^2}.$$

This formula is most easily worked in tons.

In all cases where the tension in one cable is being considered, the total load must be divided by the number of cables.

Length of cable between piers in feet $= a + \frac{8d^2}{3a}$; $\tan\theta = \frac{4d}{a}$; $\tan\phi = \frac{8dx}{a^2}$ and $y = \frac{4dx^2}{a^2}$. $z = x + \frac{2y^2}{3x}$.

To get the load to act vertically down HK, make JK= $\frac{1}{2}$KO. Then the vertical load on the piers H=2 × weight on cables from highest to lowest point=wa.

The following table gives stresses due to uniform loads on suspension bridges :—

Dip	Tension at Lowest Point	Tension at Highest Point.	Length of Cable between Piers.	Depression at Centre due to Elongation 1″.	Value of JK.	Value of JK.
$\frac{a}{10}$	1·25 × load	1·346 × load	1·027 × span	1·875″	2·5 HK.	2·7 HK.
$\frac{a}{11}$	1·375 ,,	1·46 ,,	1·022 ,,	2·0625″	2·75 ,,	2·93 ,,
$\frac{a}{12}$	1·5 ,,	1·58 ,,	1·0185 ,,	2·25″	3·0 ,,	3·17 ,,
$\frac{a}{13}$	1·625 ,,	1·7 ,,	1·0158 ,,	2·4375″	3·25 ,,	3·4 ,,
$\frac{a}{14}$	1·75 ,,	1·82 ,,	1·0136 ,,	2·625″	3·5 ,,	3·64 ,,
$\frac{a}{15}$	1·875 ,,	1·94 ,,	1·012 ,,	2·815″	3·75 ,,	3·88 ,,

The formula $y=\frac{4dx^2}{a^2}$ is used for finding the length of slings. Thus for a span of 200′, with dip of 20′, the slings being at 10′ intervals, would be as follows :—16·2′, 12·8′, 9·8′, 7·2′, 5·0′, 3·2′, 1·8′, 0·8′, 0·2′, and 0, up to the centre. If it were intended to hang the roadway 3′ below the cable, that length would have to be added to the above.

With a dip of $\frac{1}{10}$ or less a segment of a circle approximates closely to the true curve and may be used for taking all dimensions, which dimensions will be accurate enough for practical purposes.

The dip of the cable varies from $\frac{1}{10}$ to $\frac{1}{15}$ the span. Care should be taken that a site is chosen with banks of equal height.

For cables, use either iron chains and steel or wire ropes. Hempen ropes stretch, and give much trouble.

The great difficulty is want of stiffness with a concen-

trated load. To obviate this, use ties at the bottom laterally and vertically when feasible, and long road-bearers and stiff ribands. The handrails of the bridge can be made to act as the upper boom of a stiffening girder. The transoms should rest on the lower boom, which should be connected with the upper by diagonals and by vertical ties. This stiffening girder should be securely fastened to the ground at each end of the bridge.

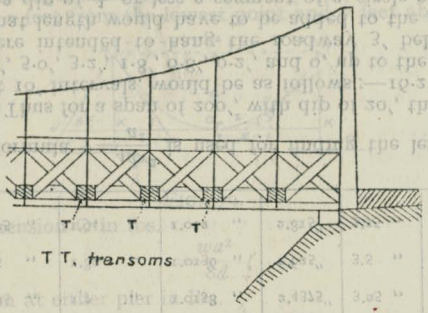


FIG. 80.

In a bridge 100′ span the scantlings of the booms of the stiffening girder need only be about $4'' \times 4''$, with $\frac{3}{4}''$ tie-rods and $4'' \times 4''$ bracing.

The anchorages should be so arranged as to make the cable form equal angles with the pierhead, and thus bring a truly vertical strain on the piers. If this cannot be done, the piers must be stayed and strutted for the oblique strains.

There are various methods of constructing suspension bridges; we will describe the most ordinary type here, as the others are based upon the same principles of construction. In this the roadway is hung below the cable; it should be at least 1′ below the cable at the centre, and should slope 1 in 30 to the centre. At the top of the piers there should be a cap of hard wood with plates to fit the cables.

It is often convenient to erect near the site of the work sheers on each side with blocks, for passing stores across, as in *Fig.* 81.

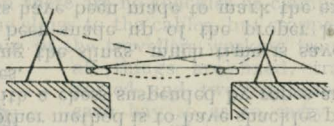


FIG. 81.

The line of bridge being fixed, anchorages are begun, and footings for piers prepared. The piers themselves are then prepared; the cable bearing should be exactly *over the centre of each standard*. The bearings and that part of the anchorage round which the cables pass should be *well greased*. While the piers are being prepared, the cables should be passed across. These piers are raised by means of back struts, props, etc., if fore guys are not available.

To raise the cable, a block is secured to the tip of each of the side struts (which have not yet been attached to the piers). These struts are then raised alongside each standard and temporarily lashed, as shown in dotted lines (*Fig.* 82). To lift the cable, a *bridle* of spun yarn is secured to it about the point where it is to bear on the cap, and the moving block is hooked to this.

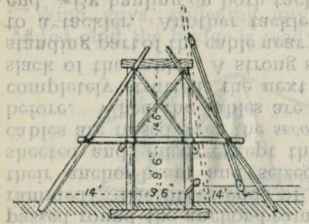


FIG. 82.

By this means the cables are raised, dropped into their places, and cleared of the bridles. The blocks are then transferred to the cap, where they are secured near the cables; the spars are partly unlashed, and their feet drawn out till they are in the proper position as struts.

When the cables are being raised, a head guy should

be used on the further side and in the plane of the pier, to steady it. These can be removed when the struts are in their proper position.

One pier having been thus raised, the cables should now be made fast to the anchorage. The ends on one side are passed round the anchor-beam and the earth filled in and rammed. The other ends of the cable are passed round their anchor-beam and seized, and the anchorages are sheeted and filled, except the cable grooves. Then the cables are raised over the *second* pier in the same way as before. When the cables are placed and the second pier completely strutted, the next operation is to take in the slack of the cable. A strong selvagee is made fast to the standing part of the cable near the anchorage and is hooked to a tackler. Another tackle is fastened to the running end. By hauling on both tackles, the cable is raised, and should be hauled up till the dip is one-twelfth or less.

There should be a man at the anchorage easing the turns; he should be careful not to entangle himself in the cable in any way, as accidents may happen through the cable slipping.

The cable, when sufficiently tightened, is seized to its standing part.

The next thing to be done is to get the slings and road transoms into position. There are two methods of working along the cable; one is by having a *traveller* composed of a spar about 3″ or 4″ in diameter, which is raised so as to rest on the cables and be kept in position by the blocks and tackle attached to the pier caps. This traveller has attached to it two rope ladders, by which access is gained to it. The other method is to have shackles passing along the cables with a chess suspended by ropes and regulated by the tackles.

In fastening the slings, much time is saved if all the slings have been made up of the proper length, and if arrangements have been made to mark the exact position of each. Each of the slings should have a shackle large enough to pass over the cable, to which it should be fastened by an eye-splice with a thimble on the steep parts; the shackle is kept from slipping by a selvagee

secured as in *Fig.* 83. Another form of fastening the slings is by a clamp screwed above and below the cable.

Even when there are no shackles or clamps, it is better not to tie the slings to the cables, but stopper them.

By means of the travellers working from both ends, all things are fixed, transoms supported, and two roadbearers placed in each bay so as to carry four or five chesses. The slings must now be adjusted. The traveller is brought directly above the third transom and two railway coupling screws are slung from the traveller, are fastened to the transom, and take its weight. The slings being slack, can then be adjusted.

FIG. 83.

If no coupling screws are available, use long spars as levers resting on the traveller, with ropes at their butts to the transoms.

The roadway is then made much as usual; the baulks, however, should be spliced so as to be continuous. After the chesses are laid, long ribands should be laid, the deeper the better, and racked to the baulks below. They stiffen the roadway and take weight off the outer baulks.

Wind guys, stiffening guys and hand-rails are then added, and the bridge is ready.

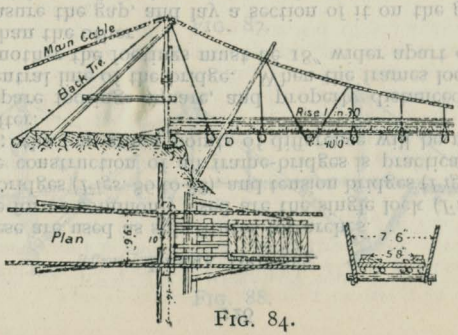


FIG. 84.

Frame Bridges.

These are used as substitutes for arches.

The forms commonly used are the single lock (*Fig.* 85), sling bridges (*Figs.* 86 to 88), and tension bridges (*Fig.* 89).

The construction of all frame-bridges is practically the same ; the few minor points of difference will be noticed hereafter.

Prepare footings square, and properly distanced from the central line of the bridge. When the frames lock into one another the footings must be 18″ wider apart on one side than the other.

Measure the gap, and lay a section of it on the ground with pickets. It is important to do this accurately and to remember that the frames only bridge the span between the footings. Lay the standards on the section and chalk-mark them at the proper positions for ledgers and transoms ; mark the centres of these and the points at which they are to be lashed to the standards. The slope of the frames should not be flatter than $\frac{1}{2}$.

To give stability, the butts should be further apart than the tips. Splay should be about 1 in 20.

Then lash the frame together. Before finally lashing the diagonal braces, see that the frame is square by measuring the diagonals.

The frame being ready, fasten fore and back guys (by clove hitches) and a foot-rope (timber hitch) to each butt.

If the frames are very heavy, derricks or props may be required to raise them, but, as a rule, they can be lifted by hand.

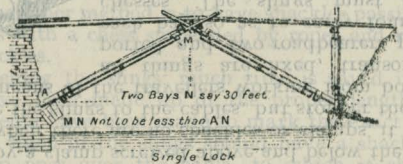


Fig. 85.

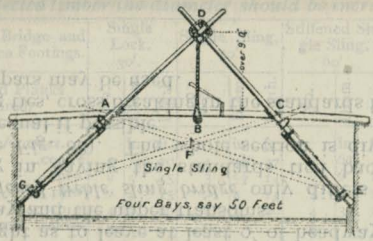


FIG. 86.

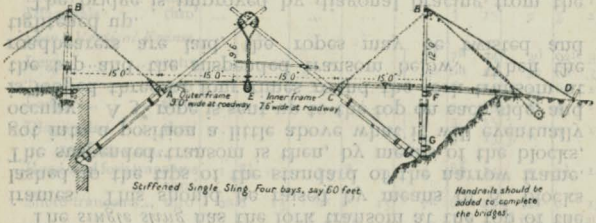


FIG. 87.

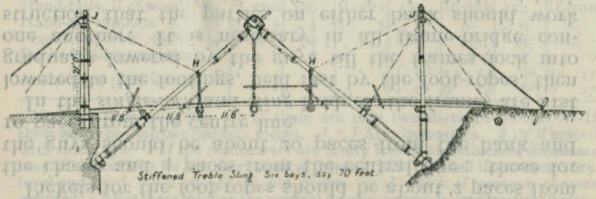


FIG. 88.

Pickets for the foot-ropes should be about 2 paces from the chasm and 4 paces from the central line; those for the guys should be about 20 paces from the bank and 10 paces from the centre line.

In the *single-lock* and *sling* bridges, the frames are first lowered to the footings, held fast by the foot-ropes, then gradually lowered by the guys till the frames lock into one another. It is necessary in all frame-bridge construction that the parties on either bank should work under the command of one officer, who should direct both fore and back guy parties, foot-rope parties, etc., moving the frames about until he is satisfied of their being in proper position.

The *single sling* has the fork transom at the top of the frames. This should be raised by means of 8″ blocks lashed to the tips of the standard of the narrow frame. The suspended transom is then, by means of the blocks, got into a position a little above what it will eventually occupy. A 3″ rope is sent up to the top on each side, and is looped three or four times round the fork transom at the top and the suspended transom below. When the roadbearers are laid, the ropes may be twisted and tightened up.

The bridge is improved by diagonal bracing from the footings to the point where the roadway crosses the opposite standard.

It must be remembered that the frames should lock at such a height as to leave at least 9′ of headway between the roadway and the upper transoms.

The *stiffened treble sling bridge* only differs from the *treble sling* in having the standards tied back at two points (see *Fig.* 88). The whole section is divided into six parts, equal if possible.

By using ties, cross breaking in the standards is avoided, and light spars may be used.

Numbers and Minimum Sizes of Spars required for Making Frame Bridges.

For unselected timber the diameter should be increased by half.

Nature of Bridge and Span between Footings.	Single Lock. 30′.			Single Sling, 50′.			Stiffened Single Sling. 60′.			Stiffened Treble Sling. 70′.		
Spars and Planks required.	No.	Diam.	L'gth.	No.	Diam.	L'gth.	No.	Diam.	L'gth.	No.	Diam.	L'gth.
2 Main Frames.		in.	ft.		in.	ft		in.	ft.		in.	ft.
Legs ... ...centre	4	$7\frac{1}{2}$[a]	20	4	$9\frac{1}{2}$[a]	37	4	6[a]	41	4	9[a]	50
Transoms ... thro'	2	5	15	3	$5\frac{1}{2}$	14	3	6	14	3	6	14
Ledgers ... ... thro'	2	4	15	2	4	15	2	4	15	2	4	15
Diagonals ... thro'	4	3	20	4	3	20	4	3	20	8	3	20
Distance pieces... thro'	0	...		0	...		0	...		0	...	
1 short Vertical Frame												
Legs ... ... centre	...	...		...	...		2	$4\frac{1}{2}$	15[g]	2d	8	24
										4e	$6\frac{1}{2}$	*24*
Transom ... thro'	...	...		...	...		1	6	12	1	6	12
Ledger ... ... thro'	...	...		...	...		1	5	15	1	5	15
Diagonals ... thro'	...	...		...	...		2	3	15	2	3	17
1 long Vertical Frame.		*			*							
Legs ... ... centre	...	...		...	...		2d	7[h]	24	2d	$9\frac{1}{2}$[h]	33
							4e	6[h]	*24*	4e	8[h]	*33*
Transom ... thro'	...	...		...	...		1	6	12	1	6	12
Ledger ... ... thro'	...	...		...	...		1	4	13	1	4	13
Diagonals ... thro'	...	...		...	...		2	3	15	4	3	17
							2	3	13			
Miscellaneous.												
Road and fork transoms thro'	1	$8\frac{1}{2}$	15	3	8	14	3	$8\frac{1}{2}$	14	5	$7\frac{1}{2}$	14
Shore transoms... thro'	2k	6	15	2k	6	15	2k	6	15	2k	6	15
Roadbearers† ... centre	10	$5\frac{1}{2}$	18	10d	5[h]	28	10d	$5\frac{1}{2}$[h]	33	10d	5[h]	26
				20e	*5*	*15*	20e	$5\frac{1}{2}$	*18*	10	5	14
										30e	*5*	*14*
Ribands† ... tip	4	3	18	4d	3	28	4d	3	33	4d	3	26
				8e	*3*	*15*	8e	*3*	*18*	4	3	14
										12e	*3*	*14*
Hand-rails, if of wood†	80	ft.-run		120	ft.-run		130	ft.-run		150	ft.-run	
Hand-rail supports ...	6	3	5	4	3	5	0	...		0	...	
Planks, 10′ × 12″ × 2″n†	34	...		54	...		64	...		74	...	
Racks for slings and ties	0	...		2	3	6	6	3	6	14	3	6
Anchorages (firm loam)	0	...		0	...		2d	12	14	2d	12	17
							6e	*6*	*14*	6e	*6*	*17*

[a] Not less than 5″ at tip. [b] If there are only two distance pieces. [c] If there are more than two distance pieces. [d, e, f] Are alternatives. [g] 12′ if braced with side guys. [h] If the roadbearers are firmly lashed at both ends, diameters may be the same as for the short vertical frame. [k] Not needed if abutments are level and hard. [m] *Throughout*, not *centre*. [n] $1\frac{1}{2}$″ thick if pontoon chesses are used. * For these bridges the vertical frames are two-legged trestles (paras. 101 to 109). † The numbers must be increased if the sides of the gap are not vertical.

Number and Sizes of Ropes Required for Making Frame Bridges.

Nature of Bridge and Span between Footings.		Single Lock. 30′.		Single Sling. 50′.		Stiffened Single Sling. 60′.		Stiffened Treble Sling. 70′.	
Rope required for	Circumference, inches.	Number.	Length, fathoms.	Number.	Length, fathoms.	Number.	Length, fathoms.	Number.	Length, fathoms.
2 *Main Frames.*									
Ties	*	...	...	...	...	4	12	8	12
Guys	3″	8	20–28	8	26–33	8	30–36	8	35–40
Foot-ropes	3″	4	9	4	9	4	9	4	9
Transoms...	2″	4	6	4	6	8	6	4	8
				4	6			4	6
Ledgers	1½″	4	6	4	8	4	6	4	8
Diagonals	1½″	4	6	8	6	...	...	4	6
Diagonals	1½″	4	6	...	6	8	6	12	6
Roadbearers	1″	0–10		10–30		10–30		20–50	
Diagonals	1½″	2		2		2		4	
Miscellaneousq	1″	20	6	18	6	28	6	36	6
Rack-lashings	...	16	...	32	...	40	...	40	...
Slings	3″	...	...	2	20–30	2	20–30	6	20–40
Falls	2″	...	...	2	20	2	20	2	20
1 *Short Vertical Frame.*									
Transoms...	2″	...	...	...	...	2	6	2	8
Ledgers	1½″	...	...	...	...	2	6	2	8
Diagonals	1½″	...	...	...	...	4	6	4	6
Diagonals	1½″	...	...	...	...	1	6	1	6
Miscellaneousq	1″	...	...	...	...	2		2–8r	
1 *Long Vertical Frame.*									
Transoms...	2″	...	...	...	...	4	6	4	8
Ledgers	1½″	...	...	...	...	2	6	2	8
Diagonals	1½″	...	...	...	...	8	6	8	6
Roadbearers	1″	...	...	...	...	4–10	6	4–10	6
Diagonals	1½″	...	...	...	...	2	6	2	6
Miscellaneous	1″	...	...	...	...	2–8r		2–8r	
Rack-lashings	...	...	...	...	...	8	...	6	...

* Safe strength of each to be 2½ tons.

q Including hand-rail supports and wooden hand-rail.

r Eight if each leg consists of two spars lashed in three places.

Tension Bridges.

When the span exceeds 60′ or 70′, or when long standards cannot be procured, tension bridges may be found suitable. Their advantages are :—

1. Suitable for large spans.
2. Ties are more easily transported than timber.
3. Roadway is very rigid.

Disadvantages :—

1. They take longer to make than frame bridges.
2. They are generally suitable for narrow roadways only.

In *Fig.* 89 a drawing of one end of a strutted tension bridge for 100′ span is shown. The height of the piers should not be less, and may be more, than one-fourth span.

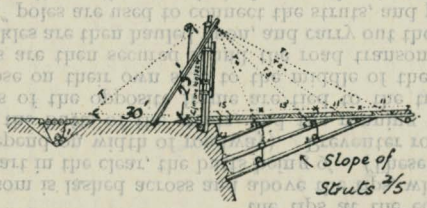


Fig. 89.

To construct the bridge, mark out the section and fix position of road transoms and vertical frames. Then make excavation for anchorages. Then make the vertical frames, taking care to stiffen the standards by extra pieces lashed alongside of them at several points. An 8″ snatch block is secured outside the tip of each standard (which should be 2′ or 3′ above the transom) ; a 3″ rope is rove through it, and passed through another snatch block secured to each standard 3′ above the ground.

The frames on each bank being ready, and each having back struts lashed to their tips while on the ground, the first frame is raised by fore and back guys. After the

frame is raised vertically, the side struts (*Fig.* 90) are raised by the blocks and tackle, and their feet and those of the back struts are bedded in the ground, and their tips lashed to the tops of the frame.

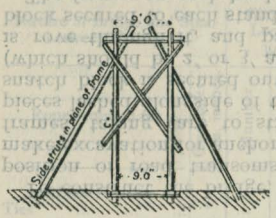


FIG. 90.

The second frame having been similarly raised, strutted, and secured, the outer pair of road struts on either side are laid between the legs of the vertical frame with the tips at the edge. A 6″ transom is lashed across and above the tips, which are 7′ 6″ apart in the clear, the butts being 9′. (These dimensions depend on width of roadway). Preventer ropes are tied to the butts of the struts, and the running ends of the falls of the opposite frame are tied to the transom, and those on their own side to the middle of the struts. The ties are then secured round the road transom. The four tackles are then hauled upon, and carry out the struts. Slight 3″ poles are used to connect the struts, and prevent lateral bending; these are lashed on as the struts go out. When the feet of the struts are let into the footings, the ties are hauled upon till they take the weight of the transoms; their land ends are then secured by anchorage and tackles cast off. The inner struts are got out in the same way, and the roadway is completed. Lastly, the central ties are secured to the central transom and got into place, the ends are anchored, and the slack taken in. The central bays are then completed.

When the ties have been lashed to the frame transoms, the back guys may be taken off. Steadying guys should be brought from the ends of the central road transom, crossed under the roadway, and brought to the opposite bank, then hauled taut, and fastened to land ties well to the right and left of the bridge.

A *tension bridge without struts* is constructed on similar

principles to the above. The roadbearers are got out with their transoms lashed to them ; as each transom leaves the bank its ties are secured to it outside the outer roadbearers. The ties are made taut, so as to give more camber than 1 in 20, and the ties secured to the pier transoms as before.

The anchorages advisable for such bridges are similar to those for suspension bridges.

Numbers and Minimum Sizes of Spars and Ropes required for making Tension Bridges.

For Unselected Timber the Diameters should be increased by half.

Nature of Bridge and Span between Footings.	Strutted Tension Bridge. 100′.			Unstrutted Tension Bridge. 80′.			Remarks.
Spars required.	No.	Diam.	Length.	No.	Diam.	Length.	
		in.	ft.		in.	ft.	
Struts C_1 ... ... centre	4	$8\frac{1}{2}$[a]	45	...	...	...	[a] 5″ is enough if thoroughly cross-braced every 15′.
Struts C_2 ... ... centre	4	7[a]	33	...	...	...	
Struts C_3 ... ... centre	4	$4\frac{1}{2}$	18	...	...	...	
Road transoms ... ... thro'	7	7	9	5	7	9	
Road-bearers—							
5″ in diameter at 6′ from either end.							
B { 10	...	...	17	B { 10	...	17	
B { 10	...	...	15	B { 10	...	12	Either B or B_1 and either C, C_1, or C_2.
B_1 10	...	...	30	B_1 10	...	27	
C 10	...	...	24	C 20	...	17	
C_1 20	...	...	13	...	...	...	
C_2 { 5	...	...	24	...	...	...	
C_2 { 10	...	...	13	...	...	...	
Ribands	Same size as roadbearers, and two-fifths as many.						
Hand-rail and supports and for racking ties, etc.	350 feet-run			200 feet-run			3″ diameter.
Frame transoms ... ... thro'	2	7	12	2	7	12	E if legs are single spars.
Frame legs ... ... centre	E 4	$9\frac{1}{2}$	28	E 4	7	23	E_1 if 3 spars to each leg.
	E_1 12	6	28	E_1 12	5	23	

Numbers and Minimum Sizes of Spars and Ropes, etc.—*Cont.*

For Unselected Timber the Diameters should be increased by half.

Nature of Bridge and Span between Footings.	Strutted Tension Bridge. 100′.			Unstrutted Tension Bridge. 80′.			Remarks.
Spars required.	No.	Diam.	Length.	No.	Diam.	Length.	
		in.	ft.		in.	ft.	
Frame ledgers ... ... thro'	2	8	14	6	7	14	
Frame struts ... ... centre	8	5	32	8	5	28	
Diagonals ... ... centre	4	4	18	4	4	18	
Anchorages (firm loam)	F	12	14	F 2	12	14	F or F_1, buried 3′ deep.
	F_1 6	8	14	F_1 6	8	14	
Chesses	G 75	12×1½	10	G 60	12×1½	10	G if laid askew.
	G_1 104	12×1½	7½	G_1 84	12×1½	7½	G_1 if laid straight.
Cordage required.	No.	Circumference.	Length.	No.	Circumference.	Length.	
		tons.h	fathoms.		tons.h	fathoms.	
Ties T_1	2	1·6h	38	2	2h	34	h These are the necessary safe strengths in tons.
Ties T_2	4	1·6h	18	4	2½h	15	
Ties T_3	4	1·6h	17	4	1¾h	14	
Ties T_4	4	1·6h	16	...	...	...	

Ropes or chains

Numbers and Minimum Sizes of Spars and Ropes, etc.—*Cont.*

For Unselected Timber the Diameters should be increased by half.

Nature of Bridge and Span between Footings.	Strutted Tension Bridge. 100'.			Unstrutted Tension Bridge. 80'.			Remarks.
Cordage required.	No.	Circumference.	Length.	No.	Circumference.	Length.	
		in.	fathoms.		in.	fathoms.	
Guys	4	3	35	4	3	30	
Falls	4			4			
Footropes	4	3	6	4	3	6	
Frame transoms	4	2	8	4	2	8	
Frame ledgers	4			4			
Road transoms	14	2	6	10	2	6	
Frame struts	12	1½	6	12	1½	6	
Roadbearers	28–50	1	6	25	...	...	
Braces E, F, etc.	12			0			
Diagonals	8			8	1	6	
Diagonals	2			2			
Hand-rails, etc.	40	1	3½	20	1	3½	
Holdfasts	16			16			

Railway Bridges (*see also Section X.*).

Trestles.

For heights of more than 25′ trestles should be built in two or more tiers, and it will be found convenient and is stronger construction to make the capsills of each tier of trestles all on the same level. The gradient if any is taken by the top tier. No tier above the lowest one should be more than about 15′ in height.

With all trestles of more than one tier it is essential to tie the junctions longitudinally by stringers.

In all trestle bridges except very low ones, longitudinal diagonal bracing should be used in each tier of trestles to stiffen the structure.

Make the trestles in a base workship if possible.

Erection of Trestles.

Trestles may be erected in the following ways :—

(1). The trestles are put together on the ground, with the bottom sill so placed that it will be in its proper position when the trestle is raised. If the ground is uneven a staging should be made on which to assemble the trestle. When ready it is raised by means of tackle reaching from near the head of the trestle to rail level. As a rule, derricks will not be necessary. It will generally be best to hook the tackle to a sling fastened near the top of the uprights and not round the capsill. Care must be taken not to rack the trestle during the operation of raising. This is more likely to occur with trestles put together with dogs than these with drift-bolts, because dogs can only be driven on one side of the trestle before it is raised. Preventer ropes must not be omitted. As soon as the trestle is upright and in its correct position it should be braced to the last one already in bridge. The rail-bearers are then got out and fixed.

Where trestles cannot be put together at the exact spot for their erection, the assembling can be done at some convenient place close at hand, where they can be carried into position. Only trestles below 16′ in height can be handled in this way.

(2). The trestles are put together on the bank and then picked up and placed in position by means of an improvised crane running on the rails, which are laid on the bridge as it progresses. This crane may be formed of a couple of trussed 12″ × 12″ timbers 5′ to 6′ longer than twice the interval between the trestles. It should be mounted on a truck axle by means of a pair of axle plummer blocks, or better still on the floor of a truck. The tail of the crane should be secured to a loaded truck behind it.

(3). Derricks are erected on either side at bank level and the trestles placed by means of the two derricks working together. This may be feasible in the case of narrow gaps where method (1) is not applicable.

(4). The trestles are built up in their positions. In an awkward site and with heavy timbers this will probably be the quickest method. The trestles should have been fitted together previously and the pieces numbered. An overhead cableway will assist materially in the erection of a long bridge.

Where there is more than one tier of trestles to be placed any of the above methods may be employed. In the case of Method (1), after the bottom tier is placed a temporary platform must be laid on the longitudinal stringers joining the capsills of the trestles. The next tier may then be assembled on this platform and raised as before.

Rail-Bearers.

The track is supported on longitudinal beams, simple or trussed, termed rail-bearers. The weight of the locomotive and the dimensions of the available material will determine the length of the bays and the number of

rail-bearers. In the case of timber bridges the spans of simple beams should not usually exceed 20′, or 35′ in the case of trussed beams.

In calculating the size and number of rail-bearers it is usually assumed that the locomotive brings a distributed load on the bridge, the amount depending upon the span and the axle loads. By this means the difficulty of ascertaining the maximum bending moment due to several moving loads on a beam is eliminated. When more than one rail-bearer has to be used under each rail they may be grouped as shown on *Figs.* 91 to 95. Here it will be observed that the rails are placed either vertically above or slightly inside the centre of the rail-bearers. At least every third sleeper should be spiked or bolted to the rail-bearers. All the rail-bearers under each rail must be securely bolted together and *fixed to the top member of the point of support.* This is best done by drift-bolts.

If the length of the available material permits, rail-bearers should extend over two bays and break joint. Rail-bearers which butt must be fastened together. A rough method of doing this is to use a dog or fishplate as shown on *Fig.* 96, but a much better method is to use cover-plates, as shown on *Fig.* 97. The bolts should be placed as in the figure.

When the rail-bearers butt care must be taken that the ends have sufficient bearing surface on the point of support. A length of 6″ of bearing surface for rail-bearers on the point of support is just sufficient provided the ends are well tied together. Sometimes a corbel or bolster is introduced, as shown in *Figs.* 98 and 99. That shown on *Fig.* 98 has the objection that it is apt to rock. Occasionally ample bearing surface can be obtained by allowing the rail-bearers to overlap on the points of support as shown on *Fig.* 91. Where two rail-bearers only overlap on the points of support, the position of the rail is vertically between them, as shown in *Fig.* 91.

Grouping and Fixing of Rail-Bearers.

FIG. 91.

FIG. 92.

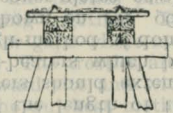


FIG. 93.

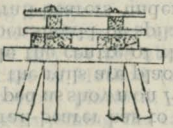


FIG. 94.

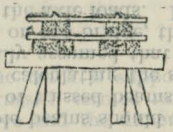


FIG 95.

FIG. 96.

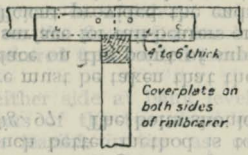


FIG. 97.

FIG. 98.

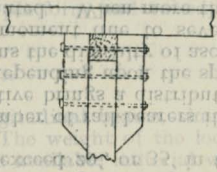


FIG. 99.

Crib Pier.

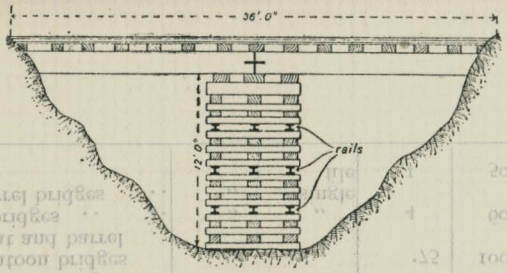


FIG. 100.

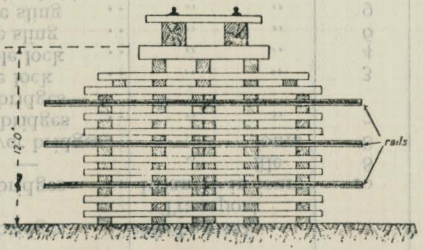


FIG. 101.

APPROXIMATE ESTIMATE OF TIME.

Below will be found a table which gives the approximate amount of time and labour required to construct certain types of military bridges.

This table is based upon actual experience in the field, but can only be regarded as a very rough guide to the framing of approximate estimates of time and labour for such nature of work.

The estimate may be taken to include all work necessary in ordinary cases, but does not include heavy work connected with approaches.

The whole of the material required is assumed to be on the ground, at the site of the bridge.

Type of Bridge.	Designed to carry—	Man-hours per foot-run.	Maximum Economical Party.
Girder bridges ..	Mechanical Transport		
Girder bridges ..	Infantry in fours	10	50
—	,, file	8	50
Cantilever bridges	,, fours	8	70
Trestle bridges ..	,, ,,	7	60
Frame bridges—			
Single lock ..	,, ,,	3	30
Double lock ..	,, ,,	4	50
Single sling ..	,, ,,	6	70
Treble sling ..	,, ,,	9	70
Suspension bridges	,, ,,	12	40
—	,, file	10	40
Tension bridges ..	,, fours	12	80
Pontoon bridges	,, ,,	·75	100
Boat and barrel bridges	,, ,,	4	60
Barrel bridges ..	,, single file	1	50

SECTION IV.

FIELD GIRDER BRIDGES.

The conditions for which these bridges are designed have been taken as follows :—

Track.—8′ 6″ between wheel guards.

Head Room above Roadway.—For motor omnibuses and large traction engines, 14′ 6″. For other vehicles, 12′.

Loads on Bridges.—All semi-permanent bridges should be designed to carry the heaviest motor transport likely to come upon them.

The bridge should be designed to take the greatest number of lorries that can reasonably be expected to come on the bridge at one time, and not to take one lorry only.

Two types of bridge will be considered in a general manner. Hard and fast types are not given, as circumstances, material available, etc., must vary with each particular case. The two types taken will be a plate girder and an " N " girder.

Plate Girder.

Having calculated the maximum bending moment that the live load can bring upon the bridge, convert this to equivalent dead load, and add the bending moment due to the weight of the structure of the bridge itself. Having decided on the number of girders, this load is then divided

equally between them, giving the maximum bending moment (Mff) on each girder. If more than four girders are used, the distribution of the Mff between them will have to be considered.

Booms.—To find the sectional area of the top and bottom booms the following formula, which gives the sectional area of each, is used :—

$$M_r = rAd,$$

where $M_r = M_{ff}$

r = maximum stress per square inch timber will take.

A = sectional area of one boom in square inches.

d = effective depth of the girder in inches.

The depth of the girder should be about $\frac{1}{14}$ of the span, and should not be more than 7′. d, the effective depth, is measured from the neutral axis of the top boom to the neutral axis of the bottom boom. With the roadway carried on the top of the girders, the top boom is in compression, and the bottom boom in tension.

Let us assume that, from the above formula, it has been found that three $9'' \times 3''$ are necessary for either boom, $9'' \times 3''$ being the timber available. Then a fourth $9'' \times 3''$ should be added as a cover plate throughout the length of the boom. The bending moment is greatest at the centre, so keep the boom joints away from it.

The maximum strength of one piece of $9'' \times 3''$ is $9 \times 3 \times r$. If bolts of diameter x'' are available the greatest stress one bolt can carry is $x \times 3 \times r$. Then the maximum number of bolts on each side of each joint in the boom will be $\frac{9 \times 3 \times r}{x \times 3 \times r}$. If nails only are available, the number of nails required can be arrived at in a similar manner to the above, the holding power of a nail being taken from the table. If bolts and nails are available fewer bolts could be used, and the deficiency made up with nails.

Web.

This is formed of planks, and the required thickness can be found from the formula :—

$$d \times t \times m = W,$$

where t is the required thickness in inches,
d is the effective depth of the girder in inches,
m is the mean of shear value with and across the grain of the timber in question,
W is the total maximum shear, which will be found from arranging loads so that the heaviest axle weight is just on the bridge at one abutment.

Bolts through Web and Flanges.—Using same symbols as for the web. Let n be the number of bolts required, and x'' be the diameter of the bolts.

For a length of d'' the shearing force = W.

Hence $$n \times x \times t \times r = W,$$

and $\frac{d}{n}$ gives us the distance apart of the bolts. If bolts and nails are available, the bolts could be interspersed with nails. Remember that the shear rapidly diminishes from the abutments towards the centre of the bridge.

The bolts will be kept well away from the ends of the web planks.

Let l be this distance from the ends of the planks.

Let y be the shearing strength of the timber with the grain.

Let a'' be the thickness of one plank.

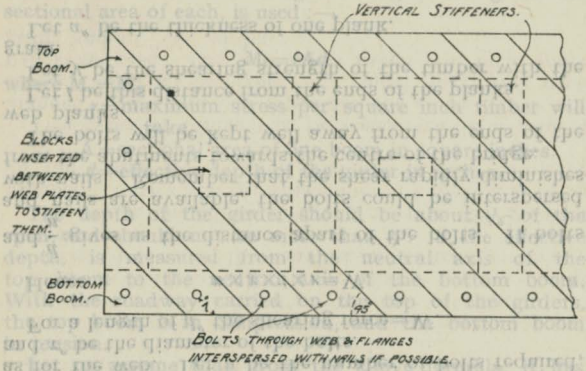
Then $$2 \times a \times l \times y = x \times a \times r.$$

Vertical Stiffeners.—These are calculated as struts which have to carry a thrust equal to the maximum shear.

The maximum reaction is W. A strut of sectional area capable of taking a thrust W is required. Let l be the length of a vertical stiffener and d its least dimension.

Having found the value for $\frac{l}{d}$ the safe r_c is taken from the table of struts.

Space them $\frac{2}{3}$ of their height apart.


VERTICAL STIFFENERS.
TOP BOOM.
BLOCKS INSERTED BETWEEN WEB PLATES TO STIFFEN THEM.
BOTTOM BOOM.
BOLTS THROUGH WEB & FLANGES INTERSPERSED WITH NAILS IF POSSIBLE.

With deep girders a diagonal from the top of one vertical to the bottom of the next may be inserted instead of the blocks (as shown in the figure) to stiffen the web plates. This halves the length of all the compression planks.

Two or four systems of planking may be used for the web (running diagonally at 45° in opposite directions). One or two systems, as the case may be, on opposite sides of the booms.

The layer or layers sloping upwards and inwards will take compression stresses and that or those upwards and outwards will take tensile stresses.

Vertical stiffeners should be secured to booms with hoop iron, chocs, etc.

The roadway can be carried on the upper booms, and wheel guides laid.

The upper booms are stiffened by the roadway, and the lower booms have cross-bracing spiked on.

The girders should be cross-braced at their ends, and at intermediate sections.

The girders should be secured to bedplates at the abutments, and these bedplates themselves should be well secured, bolted down to the masonry if the abutment is of masonry, etc.

SAFE STRESS IN RECTANGULAR TIMBER STRUTS, ENDS FLAT OR FIXED.

Ratio of Length to Least Dimension. $\frac{l}{d}$	Safe Stress in lbs. per sq. inch.	Baltic Fir or Deodar, lbs. per sq. inch.
8	r_c	1,200
9	$\frac{5}{6} r_c$	1,000
10	$\frac{2}{3} r_c$	800
12	$\frac{7}{12} r_c$	700
15	$\frac{1}{2} r_c$	600
20	$\frac{5}{12} r_c$	500
22	$\frac{1}{3} r_c$	400
25	$\frac{7}{24} r_c$	350
30	$\frac{1}{4} r_c$	300
40	$\frac{1}{6} r_c$	200
50	$\frac{1}{8} r_c$	150
60	$\frac{1}{10} r_c$	120

r_c is the *safe* resistance to crushing per square inch of a short column of the timber used.

If ends are rounded, take double the value of $\frac{l}{d}$ in the above table. If the strut is a spar of diameter d, the safe stress in the above table must be multiplied by 0·6.

"N" Girder.

The calculation of the stresses in these girders is on the same principle whether the roadway is carried on the top or bottom boom.

The girder is divided into a convenient number of panel points according to the span.

Let the maximum moving load per panel point be w. The load due to the structure of the bridge is also found for each panel point, and this is the permanent dead load, which we will call p.

We now proceed to find the stresses in the various members by the method of sections.

All moments counter-clockwise will be considered positive and *vice versâ;* similarly all tensile forces and stresses will be considered positive, and compressive ones negative.

Fig. 1 represents the girder, carrying a dead load of p lbs. at any panel point and maximum moving load of w lbs. at each panel point.

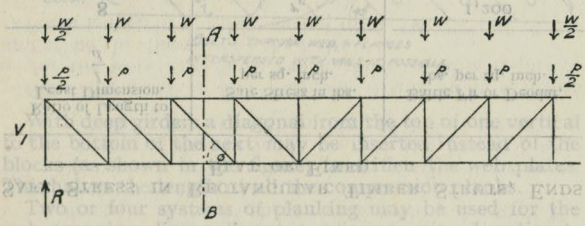


Fig. 1.

The stress in V_1 will be a maximum when the reaction R is a maximum.

Suppose the stress in the diagonal cut by the line AB to be required. Let x be the stress in the diagonal, then $x \sin \phi$ is the vertical component of this force, and therefore

$$-x \sin \phi - 2\tfrac{1}{2}(w+p)+R=0,$$

whence x is obtained, for the algebraic sum of all the vertical forces must = zero (*Fig.* 2).

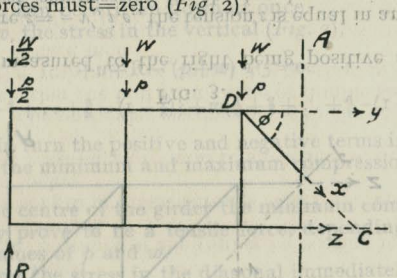


FIG. 2.

Forces acting upwards being positive and *vice versâ*. Substitute for R its value, viz. :—

$$\left\{p(\tfrac{1}{8}+\tfrac{2}{8}+\tfrac{3}{8}+\ldots+\tfrac{7}{8})+w\ (\tfrac{1}{8}+\tfrac{2}{8}+\tfrac{3}{8}+\ldots+\tfrac{7}{8})+\frac{w}{2}+\frac{p}{2}\right\}$$

and rearrange the equation $-x\sin\phi - 2\tfrac{1}{2}(w+p)+R=0$ as follows :—

$$-x\sin\phi+p\left\{\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{5}{8}-(1-\tfrac{6}{8})-(1-\tfrac{7}{8})\right\}$$
$$+w\left\{\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{5}{8}-(1-\tfrac{6}{8})-(1-\tfrac{7}{8})\right\}=0.$$

Now the terms involving w represent the moving load, and therefore it is obvious that if we leave out the two minus terms, $w\{-(1-\frac{6}{8})-(1-\frac{7}{8})\}$, we get the maximum stress value for x, and that if we leave out the five positive terms, $w\{\frac{1}{8}+\frac{2}{8}+\ldots+\frac{5}{8}\}$, we get the minimum stress value for x, *i.e.*, the greatest tension in the diagonal in question is given by the equation

$$-x\sin\phi+p(1\tfrac{1}{2})+w\left\{\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{5}{8}\right\}=0$$

and that the least tension (or greatest compression) in this diagonal is given by the equation

$$-x\sin\phi+p(1\tfrac{1}{2})-w\left\{(1-\tfrac{6}{8})+(1-\tfrac{7}{8})\right\}=0.$$

As the terms involving p represent permanent dead load, no alteration in their case is possible. Hence when the moving load covers the girder from the right abutment up to but exclusive of D, the stress in the diagonal is a maximum, and *vice versâ* (*Fig.* 2).

The stresses in the booms y and z can be obtained by taking moments round C and D respectively. Let b be the length of one bay or panel and d the height, then

$$-(y \times d) + (R \times 3b) + (w+p)\left\{b + 2b + \frac{3b}{2}\right\} = 0$$

or $-(y \times d) - (p+w)\left\{(\frac{1}{8}+\frac{2}{8}+\ldots+\frac{8}{8})\ 3b + (\frac{9}{8}3b - b) + (\frac{7}{8}3b - 2b)\right\} = 0,$

whence we see that the compression y is a maximum when the girder is fully loaded.

To find z we can either take moments round D, whence

$$(z \times d) - (p+w)\left\{(\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{8}{8})2b + (\tfrac{7}{8}2b - b)\right\} = 0$$

or we can take a section EF as in *Fig.* 3, whence $z + y' = 0$.

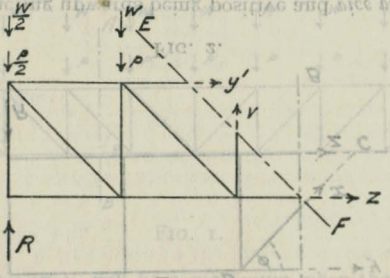


FIG. 3.

Forces measured to the right being positive and *vice versâ*.

Therefore $z = -y'$, *i.e.*, the tension z is equal in amount to the greatest compression in the top boom piece of the panel next it, towards the nearest abutment, so that

when the various values of y have been ascertained the values of z can be written down at once.

To find v, the stress in the vertical (*Fig.* 3),

$$+v+R-(p+w)\ 1{\cdot}5=0.$$

$$\therefore v+p\left\{\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{6}{8}-(1-\tfrac{7}{8})\right\}+w\left\{\tfrac{1}{8}+\tfrac{2}{8}+\ldots+\tfrac{6}{8}-(1-\tfrac{7}{8})\right\}=0.$$

Omitting in turn the positive and negative terms involving w, we get the minimum and maximum compression values for v.

Near the centre of the girder the minimum compression value may prove to be a tensile force, depending on the relative values of p and w.

If we find the stress in the diagonal immediately to the left of v, we get

$$-x\sin\phi+R-(p+w)1{\cdot}5=0, \text{ whence } -x\sin\phi=v.$$

If therefore we find the maximum and minimum values of v at each vertical, we can write down the corresponding values for the diagonal meeting it at its foot by putting

$$x=-\frac{v}{\sin\phi}.$$

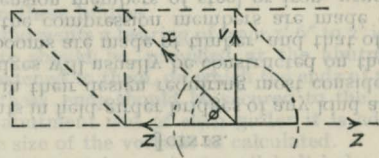


FIG. 4.

It will be seen that results are obtained at sight, which would require considerable time to arrive at, if only graphic stress diagrams were used.

A vertical can only be in tension when the diagonals meeting it at an unloaded joint are in compression. If therefore we cross-brace those panels in which from calculation we see that the diagonals undergo a reversal of stress, we shall relieve the diagonals and the verticals in question of all reverse stresses.

Joints.

The joints in field-girder bridges of any kind are perhaps the point in their design requiring most consideration.

The bridges will usually be constructed on the principle that the booms are made of timber, and that of the other members the compression members are made of timber, and the tension members of steel or iron, usually in the form of flat bars or rods.

The joints are usually made with bolts, and the main points to be considered are :—

(1). The bolt bearing into the timber.

(2). The bolt failing by shear due to the stresses in the members it unites.

(3). The bolt bearing into the members it unites.

To consider these cases :—

Let d be the diameter of the bolt in inches.

l the length of timber through which the bolt passes in inches.

r_c the resistance of the timber to bearing in lbs. per square inch.

x the length of metal through which the bolt passes in inches.

r_s the resistance of metal to shear in lbs. per square inch.

The particular circumstances of the case decide whether the bolt is in single or double shear.

r_b the resistance of metal to bearing in lbs. per square inch.

(1.). Bolt bearing into timber.

Bearing strength of one bolt is

$$d \times l \times r_c.$$

(ii.). Bolt failing by shear.

Strength of one bolt in shear (whether single or double shear depends on circumstances of the particular case) is

$$\frac{\pi d^2}{4} \times r_s.$$

(3). Bolt bearing into members.

Bearing value of one bolt is

$$d \times x \times r_b.$$

The size of bolts, etc., is fixed by what are available on the spot, and from the above cases, the one which gives the greatest number of bolts is the one which fixes the number of bolts required for a particular joint.

Any other points which arise in considering these joints, such as the distance bolts must be placed from the edge of plates or timbers, so as not to shear through them, etc., would be dealt with on similar lines to those indicated.

On these lines any joint of a field bridge can be calculated.

Bolt and nut joints are strengthened by friction between the members, but for obvious reasons this should not be relied upon in calculating the joints for field bridges.

GENERAL REMARKS ON DESIGN AND CONSTRUCTION.

A camber of about 4″ in 100′ should be given, whenever possible, in these bridges.

At the abutments a bearing of from 1′ 6″ to 2′ is required. A bedplate should be provided at the abutments, and securely fastened to them, on which the ends of the girders rest, and these ends should be secured to the bedplates.

At the abutment end of each girder it is advisable to double the size of the vertical as calculated.

Deductions must be made for all bolt-holes in tension members. If bolts do not entirely fill bolt-holes in compression members they should also be deducted. The diameter of bolt-holes on a section at right angles to its direction being deducted from the breadth or depth, as the case may be, of any particular member.

When converting live load to dead it is advisable to multiply by 2.

The joints between the laminated members of the booms should be kept as far away from the centre of the span as possible.

Girders should be cross-braced at their ends, and at intervals of about 12′ across the span.

Longitudinal bracing should be attached to the underside of the girders.

Timber Girder Bridges.—Field Working Stresses.

The stresses in timber are safe provided moderate care is taken to inspect for defects *particularly in tension members*. For good timber they are low, but have been adopted in order to allow for hasty selection.

Timber in tension, with the grain	1,000 lbs. per sq. in.	— 9 cwt. per sq. in.
Timber in tension, across the grain	100 ,, ,,	— 1 ,, ,,
Timber in compression, with the grain, columns length under 15 times least side	1,000 ,, ,,	— 9 ,, ,
Timber in compression, with the grain, end bearing	1,200 ,, ,,	—11 ,, ,,
Timber in compression, across the grain	250 ,, ,,	— 2½ ,, ,,
Timber in shear, with the grain	150 ,, ,,	— 1⅓ ,, ,,
Timber in shear, across the grain	450 ,, ,,	— 4 ,, ,,
Timber, transversely loaded	1,000 ,, ,,	— 9 ,, ,,

Lateral Resistance.

Nails, wire, iron, grooved	6 in., each	200 lbs.— 1¾ cwt.
,, ,, ,,	5 ,, ,,	160 ,, — 1⅝ ,,
,, ,, ,,	4 ,, ,,	90 ,, — ⅝ ,,
,, ,, ,,	3 ,, ,,	70 ,, — ⅝ ,,
,, iron, spike	9 ,, ,,	1,000 ,, — 9 ,,
,, ,, ,,	8¼ ,, ,,	900 ,, — 8 ,,
,, ,, ,,	7 ,, ,,	700 ,, — 6 ,,
,, ,, ,,	6¼ ,, ,,	450 ,, — 4 ,,
Screws	Diam., ⅞ in.	Length, 5 in. ,, 2,800 ,, —25 ,,
,,	,, ¾ ,,	,, 4½ ,, ,, 2,100 ,, —19 ,,
,,	,, ⅝ ,,	,, 4 ,, ,, 1,650 ,, —14 ,,
,,	,, ½ ,,	,, 4 ,, ,, 1,100 ,, —10 ,,
,,	,, ⅜ ,,	,, 3½ ,, ,, 700 ,, — 6¼ ,,
Bolts and rivets	Diam., 1 in.	Area, ·7854 in. Double shear—140 ,,
,, ,,	,, ⅞ ,,	,, ·6013 ,, ,, ,, —110 ,,
,, ,,	,, ¾ ,,	,, ·4418 ,, ,, ,, — 80 ,,
,, ,,	,, ⅝ ,,	,, ·3068 ,, ,, ,, — 55 ,,
,, ,,	,, ½ ,,	,, ·1963 ,, ,, ,, — 35 ,,
,, ,,	,, ⅜ ,,	,, ·1104 ,, ,, ,, — 20 ,,

In single shear deduct ⅜ from values for double shear.

Working Stresses for Metals in Tons per Square Inch.

Material.	Tension.	Compression.	Shear.	Bearing.	Modulus of Elasticity.	Weight per Cubic Ft. in lbs.
Cast Iron...	1·5	9	2·4	10	6,250	450
Wrought-Iron Bars	6	5	5	5	13,000	480
Wrought-Iron Plates	5	4	5	5	12,000	480
Wrought-Iron Rivets	—	—	4	6	—	480
Mild Steel	7·5	6·5	5·5	8	13,400	490
Steel Rivets	—	—	5·5	8	—	490

N.B.—In *heavy* girder work a bearing value of 11 can be worked to with mild steel, wrought-iron rivets, if in *double* shear, have a value of $3\frac{1}{4}$ only, instead of 4. Steel rivets, if in *double* shear, have a value of 4·5 only, instead of 5·5.

Steel Rivets and Bolts. Working Stresses.

Table of Maximum Safe Shearing and Bearing Values in Tons.

Diam. of Rivet.	Area of Rivet.	Maximum Shear.*		Bearing Values of Plates of Various Thicknesses at 8 Tons.*							
Inches.	Sq. Ins.	Single at 5·5 Tons.	Double at 9 Tons.	$\frac{1}{4}$"	$\frac{5}{16}$"	$\frac{3}{8}$"	$\frac{7}{16}$"	$\frac{1}{2}$"	$\frac{9}{16}$"	$\frac{5}{8}$"	$\frac{11}{16}$"
$\frac{1}{2}$	·1104	·607	0·994	0·750	0·938	1·125					
$\frac{9}{16}$	·1963	1·079	1·767	1·000	1·250	1·500	1·750				
$\frac{5}{8}$	·3068	1·687	2·761	1·250	1·562	1·875	2·188	2·500			
$\frac{3}{4}$	·4418	2·430	3·976	1·500	1·875	2·250	2·625	3·000	3·375	3·750	4·125
$\frac{7}{8}$	·6013	3·307	5·412	1·750	2·188	2·625	3·062	3·500	3·938	4·375	4·812
1	·7854	4·319	7·069	2·000	2·500	3·000	3·500	4·000	4·500	5·000	5·500

*N.B.—In light work, *e.g.*, roof trusses, take the resistance of rivets in double shear at $7\frac{1}{2}$ tons, and in bearing at 6 tons per square inch.

Whitworth's Standard Nuts and Bolt-Heads.

Diam. of Bolt, inches.	Width across Flats.	Thickness of Nuts.	Thickness of Bolt-Heads.	Diameter of Bolt at Bottom of Thread.
$\frac{1}{8}$	·338	$\frac{1}{8}$	·1093	·0929
$\frac{3}{16}$	·448	$\frac{3}{16}$	·1640	·1341
$\frac{1}{4}$	·525	$\frac{1}{4}$	·2187	·1859
$\frac{5}{16}$	·6014	$\frac{5}{16}$	·2734	·2413
$\frac{3}{8}$	·7094	$\frac{3}{8}$	·3281	·2949
$\frac{7}{16}$	·8204	$\frac{7}{16}$	·3828	·346
$\frac{1}{2}$	·9191	$\frac{1}{2}$	·4375	·3932
$\frac{9}{16}$	1·011	$\frac{9}{16}$	·4921	·4557
$\frac{5}{8}$	1·101	$\frac{5}{8}$	·5468	·5085
$\frac{11}{16}$	1·201	$\frac{11}{16}$	·6015	·571
$\frac{3}{4}$	1·3012	$\frac{3}{4}$	·6562	·6219
$\frac{13}{16}$	1·39	$\frac{13}{16}$	·7109	·6844
$\frac{7}{8}$	1·4788	$\frac{7}{8}$	·7656	·7327
$\frac{15}{16}$	1·5745	$\frac{15}{16}$	·8203	·7952
1	1·6701	1	·875	·8399
$1\frac{1}{8}$	1·8605	$1\frac{1}{8}$	·9843	·942
$1\frac{1}{4}$	2·0483	$1\frac{1}{4}$	1·0937	1·067
$1\frac{3}{8}$	2·2146	$1\frac{3}{8}$	1·2031	1·1615
$1\frac{1}{2}$	2·4134	$1\frac{1}{2}$	1·3125	1·2865
$1\frac{5}{8}$	2·5763	$1\frac{5}{8}$	1·4218	1·3688
$1\frac{3}{4}$	2·7578	$1\frac{3}{4}$	1·5312	1·4938
$1\frac{7}{8}$	3·0183	$1\frac{7}{8}$	1·6406	1·5904
2	3·1491	2	1·75	1·7154
$2\frac{1}{8}$	3·337	$2\frac{1}{8}$	1·8593	1·8404
$2\frac{1}{4}$	3·546	$2\frac{1}{4}$	1·9687	1·9298
$2\frac{3}{8}$	3·75	$2\frac{3}{8}$	2·0781	2·0548
$2\frac{1}{2}$	3·894	$2\frac{1}{2}$	2·1875	2·1798
$2\frac{5}{8}$	4·049	$2\frac{5}{8}$	2·2968	2·3048
$2\frac{3}{4}$	4·181	$2\frac{3}{4}$	2·4062	2·384
3	4·531	3	2·625	2·634

SECTION V.

MINING AND DEMOLITIONS.

MINING.

Shafts are used for vertical descent, *common galleries* for ordinary horizontal travelling, *branch galleries* of smaller size for short lengths, and *great galleries* for manipulating the machines required for "bored mines."

The cases and frames for galleries have *ground sills* at the base, *stanchions* at the sides, and *top sills* above. The end pieces of frames for shafts are called *rails*, or *end rails*, and the side pieces *stiles*.

Description.	Size of Cases.				Size of Frame.					
	In the Clear.		Over All.		In the Clear.		Over All.		Thickness of Sheeting Planks.	
	Height.	Width.	Height.	Width.	Height.	Width.	Height.	Width.	Top.	Side.
	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	″	″
Great gallery	6 6	8	7 2	7 4						
Common do.	5 6	2 0	5 10	2 4	4 10	2 0	5 4	2 7	2	1½
Branch do.	4 0	2 0	4 4	2 4	3 6	2 0	4 0	2 7	2	1 or 1½
Shaft	4 0	2 0	4 4	2 4	4 0	2 0	4 7	2 7	2	2

The top frame of a shaft has horns projecting 1 foot.

Sheeting is made in lengths, generally 5′ each, the width 11″, and thickness 2″, having one end bevelled for about 6″. With these dimensions the frames can be put 4′ apart.

Cases form a better lining than frames, are stronger and safer, but take more timber.

When no timber is used, the elliptical form is best for *shafts*, the axes being 4′ and 2′. In *galleries*, the top should be arched, the miner being provided with templates.

Cases.

A case may be used like a drum curb in well-sinking, the other cases being placed above it. If this method is not used, wedge-shaped recesses must be left on opposite ends of the shaft, to enable the last piece to be put in.

The cases must be put in, with loose earth, before the earth in the centre is removed ; this is not necessary with good earth where the shaft can be dug by simply excavating to the depth of one case at a time. The cases must be flush on the inside and close together.

When it is intended to break out into a gallery, the ends of the lowest cases (5 for a branch gallery, 7 for a common gallery) are omitted for a length equal to the height of the gallery, and temporary arrangements made for holding up the sides of the shafts.

In making the gallery, its centre line is marked by pickets determined by plumb lines from above. A case is then temporarily placed upright in the shaft to take the thrust of the sides, and the first case of the gallery is placed with its inner edge flush with the inside of the shaft.

To get in the top sill, a wedge-shaped recess must be cut above each stanchion, no more earth than is necessary being removed. In good soil the cases need not be close together ; sheeting or other planks may be used, and the cases placed at intervals.

The direction of galleries should be verified after a while by the original centre line of the shaft.

In changing direction, work round the angle gradually, fitting the cases close at one side and with intervals on

the other. To set off a new angle accurately, have the angle laid down above ground and nail together pieces of battens or sticks to make the required angle; this will serve as a template for the work below.

With *trained* men, in ordinary earth, a shaft should advance from 18″ to 24″ per hour, a great gallery at 12″, a common gallery at 16″, and a branch gallery at 24″. Unskilled men can only do half these amounts.

Frames and Sheeting.

Before beginning, it is well to know the depth to go, so as to be able to regulate the distance apart of the frames. The top frame is first laid, level in all directions, and the excavations continued to the bottom of the next frame, which should correspond with the upper one in every point. Grooves are cut for the sheeting planks, which are pushed down, bevelled faces outwards, until the tops rest against the top frame and the bevelled ends against the second frame, but wedged 2″ from it so as to allow the next piece of sheeting to be forced down. Each frame is attached to the one above it by ropes or battens. When the third frame is placed, the sheeting planks are driven, displacing the wedges.

In breaking out a gallery, the frame next above the top of the intended gallery being placed with its sheeting, the excavation is continued to the level of the floor of the gallery and a frame placed at the bottom of the shaft, cutting grooves for a single thickness of sheeting only, which is placed on three sides of the shaft. The first gallery frame is placed with great accuracy, the stanchions let in their own depth into the sides of the excavation, their feet sunk about 2″ into the floor of the gallery and no ground sill used. The points to be noted in putting in subsequent frames are :—(1). See that the under sides of the top sills are level. (2). That the inner sides of the stanchions are flush with the gallery sides. (3). That the sheeting planks are pushed with their bevelled sides upwards and foremost, and separated from the frame at first by wedges to make room for the next set. (4). If the sides are shaky, use sheeting and ground sills.

Galleries in Rock.

In carrying out galleries in rock, it will be necessary to drill holes on the face, load them with explosives, and, when convenient, to fire them by electricity or time fuze (*vide infra*). The N.C.O. in charge of the party must see that any charges which have not exploded are carefully withdrawn or arranged for firing again; in the latter case, he will not allow any violent blows to be given to the rock in the vicinity. Neglect of these precautions has led to fatal accidents.

Bored Mines.

In ordinary soil much time may be gained by using "Bored Mines" at the head of the gallery.

A hole is bored in the required direction and a chamber formed at the end of it by exploding a small charge of high explosive. This chamber is then used for the reception of the mine charge. A bore-hole of from $2\frac{1}{2}''$ to $3''$ diameter is a convenient one.

Bored mines are specially useful for the defender, as the charges will necessarily be comparatively small.

Special machines are available for making bore-holes rapidly, and in large operations these would be employed. But where such machines are not available the tube well apparatus can be used. It has the drawback, however, of being noisy. The boring will have to be horizontal, or only slightly inclined, and in prolongation of a gallery on account of the length of the tubes. A wooden frame with two uprights should be made to carry the tubes, and the monkey must be worked by hand, one man on each side carrying it back and swinging it forward. The tube should be kept well oiled. Thirty feet have been bored in medium soil in this way in two hours, including fixing up and withdrawing the apparatus.

As a rule the bore-hole will require no lining, but in very soft soil a lining of tubes may have to be used. These should be made of brass.

The small charge to form the chamber must be some form of high explosive.

Assuming that only that portion of the chamber can

be loaded which is below the level of the end of the bore-hole, charges, of from 2 to 4lbs., will give chambers in ordinary soil capable of holding from 400 to 900lbs. of gunpowder.

It is not necessary to tamp either the chambering charge or the main charge. For the former a couple of filled sandbags should be placed at the mouth of the bore-hole; for the latter it is advisable to use about a dozen. In both cases it is well to withdraw the mining party behind the nearest turn in the gallery.

One method of loading the chamber is to use a long scoop at the end of a rod. The scoop is filled with the explosive to be used, passed up the bore-hole and turned half round, allowing the explosive to fall into the chamber.

In stiff soil, or when using lining tubes, the chamber may be loaded by pushing a line of several cartridges up the bore-hole at one time.

The last cartridge will contain the detonator and leads (or fuze), and must be loaded singly and with great care. The leads must be firmly tied to the cartridge.

Ventilation and Lighting.

A gallery should not be driven more than 60′ without providing for the renewal of air.

A hole may be bored from the top of the gallery with an earth borer, or a shaft may be made upwards with cases, using a long-handled push pick and protecting the worker from falling stones, etc., by a removable shield of planks resting on the cases. Failing these methods, air should be forced in by a rotary blower (Service pattern, "Blower, rotary, Mark IV.") through fans and hose. The bellows of any medium-sized forge can be fairly well used. The hose should be fastened by spun yarn lashings to nails driven in the top corner of the gallery.

For entering foul mines the Denayrouze Respirator or the Applegarth Aérophore are used. The former is for use when a man has to go a comparatively short distance, up to about 75′, into a bad atmosphere, not at a greater pressure than the outside air; it consists of a gutta-percha tube 50′ long, a tin valve box which allows air to pass out

of the tube, but none to come in, and a pair of eye protectors made of glass goggles mounted in an inflatable india-rubber mask. The mask is strapped on and inflated by another man till it sits close to the face and grips the nose. The tube is attached to the body by buckling up the waistbelt and shoulder-strap above and below the valve box, which lies in the centre of the back. The tube is strong enough to be used as a life line, and if it is anticipated that this may be necessary, should be lashed to the man.

The Aérophore consists of a helmet, with a water and gas-proof jacket, lengths of tubing and an air pump. The tubing is in lengths of 50′ with screw unions. With this apparatus work can be done at a distance of 200′ from the pump. The tube can also be used as a life line.

The use of the above apparatus requires practice, and men should be gradually accustomed to it before being sent into foul mines.

Mines may be lighted by reflecting daylight by sheets of tin, etc., or by lanterns or electric light.

During loading of mines no lights can be allowed to burn in the galleries. Sheets of glass or zinc, with luminous paint, will give all the light required.

Countermines and Subterranean Warfare.

Countermines should extend as far to the front of a defensive work as possible. They are generally in front of a salient and consist of parallel galleries going to the front, connected by lateral galleries. The most advanced are called "listeners," the nearer "galleries of communication," and the transverse ones "envelopes." The charges are placed in branch galleries. The listeners are about 30 yards apart with branches, or a maximum of 25 yards without them. The depth should be so regulated that the besiegers cannot get below them, and they should be sufficiently near the surface to allow small charges to be fired and destroy lodgments above ground. A good system is—main listeners 90′ to 120′ apart and 15′ to 18′ deep, with branches at every 40′ to the right and left, of such a length

as to place the charges far enough away from the main listeners to prevent the possibility of the destruction of the galleries.

Charges of Mines.

Guncotton and other compounds which, when exploded, give off carbonic oxide are unsuitable, as they render the ground poisonous. Hitherto gunpowder has proved the most suitable explosive for ordinary mines, but where underground working is not likely to be carried on after the explosion of the first mine, there is not the same objection to the use of high explosives.

A crater of which the diameter equals line of least resistance (LLR) is called a one-lined crater. A *common mine* is one where the diameter=2 LLR; the crater is then said to be a *two-lined* crater. Mines more heavily charged than common mines are called *overcharged*, those with smaller charges are *undercharged*, and those whose charges do not produce any craters are called *camouflets*. When the LLR of two adjacent charges is the same they are said to be at one, two, etc., lined intervals when the distance between their centres is once, twice, etc., the length of LLR. If the LLR is not the same, add the two LLR together and take $\frac{1}{2}$, $\frac{2}{2}$, $\frac{3}{2}$, etc., of the sum for the intervals.

Calculating Charges.

If l=LLR in feet, r=radius of crater in feet, c=charge of powder in lbs., s=a variable coefficient (see below), then:—

In a common mine $c=\frac{s}{10}l^3$.

,, overcharged ,, $c=\frac{s}{10}\left\{l+\cdot 9\,(r-l)\right\}^3$.

or undercharged.

As regards *camouflets*, practically any mine with a charge less than one-sixth of a common mine of the same LLR can be considered as a *camouflet*.

The values to be given to s are:—Very light earth,

0·8; common earth, 1·00; clay with loam, 1·55; rock, 2·25. *The soil should be made the subject of experiment.*

It is better to use a number of small charges to produce a certain effect than one large one.

Radius of Rupture.

A fired charge produces an internal commotion in the ground in its immediate neighbourhood. The distance from the charge to which this commotion extends is called the *radius of rupture*. Where there is no crater, the underground commotion is roughly a sphere. Where there is a crater the commotion extends to a greater distance horizontally than it does vertically.

Horizontal Radius of Rupture (HRR)—

For common mines :—

$$\text{HRR} = \tfrac{7}{4} l \text{ or } \tfrac{7}{4} \sqrt[3]{\frac{10 \cdot c}{s}}.$$

For overcharged or undercharged mines :—

$$\text{HRR} = \tfrac{7}{4} \sqrt[3]{\frac{10 \cdot c}{s}} \text{ or } \tfrac{7}{4} \{ l + \cdot 9 (r - l) \}.$$

Vertical Radius of Rupture (VRR)—

For common mines :—

$$\text{VRR} = \tfrac{7}{5} l \text{ or } \tfrac{7}{5} \sqrt[3]{\frac{10 \cdot c}{s}}.$$

For overcharged and undercharged mines this relation does not hold, as the pressure in a vertical direction is influenced by the depth of the charge.

Loading Mines.

The charge should be placed in a recess out of the direct line of the shaft or gallery. When firing with electricity it is better to put the chamber at the top of the gallery, and near the bottom if fuze is to be used.

In dry soil, the powder should be laid on straw or brushwood in bags containing 50lbs. each. In damp soil the bags should be made waterproof. India-rubber bags are

articles of store and are provided with wooden clamps. A barrel of gunpowder contains 100lbs., and 1lb. of gunpowder measures 30 cubic inches. A cube with side 30" contains 900lbs. of powder.

The charge *should be placed by an officer with his own hands*. It should be made up outside the mine as much as possible, and may be taken along the galleries in miners' trucks or passed in sandbags from hand to hand. Before beginning to tamp, the fuze or wires must be carefully placed. In all large charges there should be two points of ignition and two means of firing in case of failure.

The tamping should extend for a distance *at least* 1½ LLR, better 2 LLR. Earth, sods, sandbags, bricks may be used. It is often desirable to strengthen the tamping by pieces of timber placed diagonally, with their ends jammed into the sides of the shaft or gallery. The proportionate value of tamping decreases with the increase of charge.

At intervals in the tamping, air spaces may be left with equally good results. Thus 34′ of tamping with two air spaces, each 5′ long, has been found to act as well as if the whole were solid. The maximum amount of air space allowable is, however, uncertain.

Firing Charges without Electricity.

The usual method is with *safety fuze*. This is supplied in tins containing 8, 24 or 50 fathoms. Average rate of burning, one yard in a minute. It *may* burn 4′ a minute, but should be tested. It will burn under water.

Tie a knot at the end when putting in a powder-bag, cut off the other end diagonally, then light with a match. When only ordinary matches are available, the match head must be placed against the powder and lit with another match or by striking the box on it. If guncotton is used, a detonator (No. 8) is necessary; cut the fuze square at the end to be inserted in the detonator, push it in gently as far as it will go, and, if the fuze is loose, squeeze the end of the shank of the detonator on to the fuze. For use with No. 8 detonators, Mark VII., the fuze must be stripped.

Instantaneous fuze may be known from safety fuze by

its orange colour and by its being coated with open crossed thread. It burns at the rate of 30 yards a second. To fire it, always splice a piece of safety fuze to it, making diagonal cuts in both and tying together with string. The joint may require to be made water-tight; if so, use india-rubber tape and solution.

For firing several charges simultaneously, a small circular junction box is used, with a hole bored through the sides for each mine fuze and one for the safety fuze; the box is filled with powder in which the ends of the fuzes are buried. It is very difficult, however, to ensure simultaneous firing by the use of instantaneous fuze.

Detonating Fuze.—In order to *ensure* simultaneous firing, without employing electricity, several kinds of *detonating fuze* have been invented and may be met with. These consist of a thin column of some high explosive contained in a flexible tube (usually of metal).

All detonating fuzes must be exploded by a detonator, which is itself fired by a length of safety fuze. The envelope of the detonating fuze should be cut so as to expose the high explosive, and the exposed surface of this must be tied against the detonator. Another method is to insert the end of the detonating fuze into another detonator, place it alongside the first, and tie the two together. Occasionally metal sleeves with runners are provided with the fuze. If so they should be used, as they form the best means of joining detonator and fuze.

Joints between lengths of detonating fuze may be made in various ways :—

(1). By using a detonator at the end of each length, lashed together as above.

(2). By exposing the high explosive of each length, placing the exposed surfaces together and tying them up.

(3). By twisting the two ends together, care being taken not to damage the tubing, but there must be no play.

If several charges are to be fired simultaneously there should be one main fuze with branches off it, but in order to avoid failures one main fuze should never have more than two branches. If more than two charges are to be fired, the original branch fuzes should bifurcate, and so

fired, the original branch fuzes should bifurcate, and so

on. The angle between a branch fuze and the direction of the main one should not exceed 30 or 40 degrees.

Certain explosives can be fired by means of detonating fuze alone, good contact being secured between the two. Other explosives require a detonator as usual at the end of the fuze. This is generally necessary with guncotton.

It will be found that with each type of detonating fuze, a certain joint and method of firing, etc., will be found the most suitable. This should be ascertained by experiment before use in actual demolitions.

If a charge should fail to explode, allow at least 30 minutes from the time the fuze is lit before approaching the charge. The charge should only be withdrawn or touched when it is absolutely necessary. Guncotton and similar charges, where not in inaccessible places, can best be "killed" by placing and firing a fresh charge close to them.

Firing Mines by Electricity.

To insert fuzes into a bag of gunpowder, fill a bag one-third full, insert the fuzes, and, while holding them in place, fill up the bags with powder; give a slack of about 6″ to the wires inside the bag and lash up the mouth of the bag very firmly. Then tie up the bag with rope like a parcel, and attach any light line about 4 fathoms long. To this light line, drawn tight, seize the line and return wires, keeping them quite slack (see *Fig.* 1). If the ground is damp the charge should be put inside an india-rubber bag and closed by a clamp. (Both bag and clamps are articles of R.E. equipment). The mouth of the bag should be smeared inside with india-rubber solution.

FIG. 1.

Fuzes are used for firing gunpowder, *detonators* for guncotton, dynamite, etc. The latter can always be distinguished by having a tube, painted red, filled with fulminate of mercury. They should be handled carefully. Those usually employed in land service are No. 13 detonator and No. 14 fuze. They are fired by an electric current from a *dynamo-electric exploder*, or from a battery.

With the "exploder," all that is necessary is to draw out a handle as far as it will go, *then* attach the line-wires to the terminals, then push down the handle to the bottom and the fuzes or detonators will be fired.

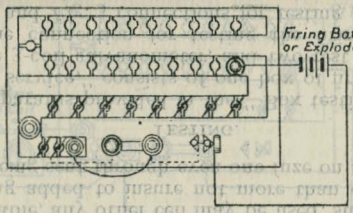
The form of battery most likely to be available for firing mines is the Leclanché. The approximate E.M.F. and resistance of this per cell are 1·5 volts and ·25 ohm.

The *Leclanché* cell consists of a carbon plate in contact with four agglomerate blocks, separated from a zinc plate by two thicknesses of coarse canvas. The zinc plate is bent to enclose the carbon plate and agglomerate blocks. The top of the cell is sealed up with bitumen and plaster of Paris, leaving two holes through which water can be poured when the battery is required. The cell is charged by pouring a concentrated solution of sal-ammoniac into the larger hole. Care must be taken that the battery does not become dry.

Calculation of Battery Power.

The following is a rough method of calculating the required battery power. With Leclanché cells, allow two cells for every fuze or detonator and one cell for every ohm in the leads and connections. *Add 50 per cent. to the results* to allow for contingencies. It is necessary that, with Leclanché's, the charges should be in series with two fuzes in series in each.

To estimate the number of charges which can be fired by a dynamo exploder, first find whether it is strong enough to enable two fuzes to be put in each. To do this the dynamo is tested with the firing resistance coils connected as in *Fig.* 2. A small resistance should be tried first and gradually increased till the machine fails. It is thus found capable of fuzing the standard wire through a certain number of ohms. If the resistance of the fuzes, or detonators, at fuzing point and of the main leads is not greater than 80 per cent. of this, the exploder may be taken as strong enough; if it is greater, one fuze, or detonator, only can be put in each charge, or the number of charges must be reduced.



When exploder is being tested, the key should be cut out with a short lead.

FIG. 2.—CONNECTIONS FOR TESTING FIRING BATTERY OR DYNAMO.

Cables.

The cables likely to be used in firing mines are :—

Vocabulary Number.		E.1 Mk. II.	E.2 Mk. I.	C 1
No. of strands in conductor	copper	6	7	3
	steel	1	0	0
Diameter of each strand in inches		·02	·028	·028
Nearest S.W.G.		25	22	22
Resistance of whole conductor per 100 yards at 60° F.	ohms	1·43	0·6	1·35
Nature of insulating material		V.I.R.	V.I.R.	V.I.R.
Nature of covering		B.	B.	P.T.
Outside diameter of covering in inches		·175	·32	·35
Weight per 1,000 yards	lbs.	57	170	334

N.B.—(1). V.I.R. = Vulcanized india rubber. P.T. = India rubber or primed tape. B = Boiled and coated with compound.

(2). E.1 is specially designed for field demolitions.
E.2 is for main connections in heavy demolitions.
C.1 is a field telegraph cable for river crossings.

Precautions in Firing Mines.

1. When testing a detonator or fuze, never attach a wire to either lead until it is in a safety box.

2. Never solder a lead to a detonator, etc., unless the latter is in a safety box.

3. Always hold a detonator, etc., pointing away from the holder and from others near.

4. Do not place detonators near strong acids.

5. Always see that the far end of the lead remains disconnected when at work. If this is impossible, make a temporary break in the circuit, within view.

6. See that there is no strain on the head of detonator, etc., especially in making up a charge.

7. See that everyone is at a safe distance when testing the complete circuit.

8. Do not bring up the firing instrument till it is wanted.

9. Put a N.C.O. in charge of the ends of leads to the charge, with orders not to let them go out of his hands, and to keep them insulated.

10. Disconnect both leads immediately after firing and give them in charge of the N.C.O.

11. If a battery is used, put the safety block in place, then connect one terminal to firing key. When the time comes for firing, first connect one lead to the other screw of firing key, and attach the other lead to the other terminal of the battery just before firing.

12. A single test cell only will be used for testing fuzes and detonators and the complete circuit; if a test cell is not available, any other cell may be used, sufficient resistance being added to insure not more than one-twentieth ampère being sent through even one fuze on short circuit.

Testing.

The apparatus provided in the "Box testing and jointing, field service," consists of one box of firing resistance coils, one 3-coil galvanometer, and two test cells. *Fig.* 2 shows the connection for testing the firing battery or dynamo, and *Fig.* 3 connections for testing the resistance of line, fuzes, etc.

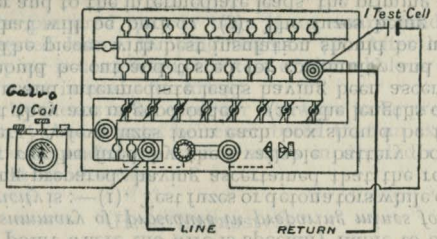


FIG. 3.—CONNECTIONS FOR TESTING RESISTANCE OF LINE, FUZES, ETC.

The 3-coil galvanometer has three coils of 2, 10, and 1,000 ohms resistance respectively, which can be put separately into circuit by a movable peg.

The "Cell, Electric, dry, E" is for testing purposes. It is a special form of dry cell similar to the Obach pattern, but provided with a resistance coil which brings the total internal resistance up to 12 ohms, thus obviating the possibility of anything but a very small current being sent out by it under any circumstances. Its E.M.F. is 1·5 volts.

In addition to the above, the testing box contains two reels of platinum wire, some covered wire (copper), chamois leather, and plate powder, for testing, and pliers, india-rubber tape and solution, and cotton waste for jointing.

Testing Cables.

The insulation of a cable for firing a charge should be at least 1,000 ohms. To test this first take the deflection on the 1,000 coil of the galvanometer with the test or any other cell on short circuit, then try what deflection the same cell will give through the insulation of the cable. If it is not greater than half the previous deflection, the cable is good enough. The test may be taken with the cable in a tank of water, or laid out on the ground.

To *localize a fault*, connect up as before and pass the cable through the water about a foot at a time. A deflection on the galvanometer will mean that a leaky portion is passing through the water.

Testing Fuzes and Wires.

When time permits, all wire fuzes and detonators should be balanced by Wheatstone's bridge, and their resistances marked. Land service fuzes and detonators should be between ·95 and 1·15 ohms. If there is not time to balance each fuze accurately, the *continuity* of each should be tested with the 2-coil and a test cell. About the same deflection should be obtained whether the fuze be in or out of circuit. Fuzes thus tested must be connected in series.

Conducting wires should always be tested for continuity by being placed in circuit with a battery and galvanometer.

In all cases, however, covered wires should be carefully examined when being paid out, to discover kinks, bare places, and bad joints.

When the mines are in position, the resistance of the complete circuit should be balanced with the test cell connections.

Jointing.

To *joint wires*, strip off each insulation 2″, and clean by scraping with the back of a knife; take care not to nick the wires. Cross the wires at right angles, and then bend them round each other, make three or four close turns at the ends, then insulate with india-rubber tape and solution, or a small piece of india rubber may be slipped over the joint and be tied at the ends. The joint is always the weak part of the circuit; it should never be at a point where the wire is specially liable to be bent.

The *summary of procedure in preparing mines for firing by electricity* is :—(1). Test fuzes or detonators while charges are being prepared, having ascertained that the requisite number *can* be fired by the available battery power or exploder. A few fuzes from each box should be fired to see that they are in good order. (2). The lengths of cable for main and intermediate leads having been ascertained, they should be cut and tested for continuity and insulation. The pieces with best insulation should be used for parts that will be buried. (3). The fuzes being jointed together and to the intermediate leads, the priming charges

should be prepared, put in bags if necessary, and each branch tested before tamping begins. (4). After loading and tamping is completed, the test of the whole is taken, and the mine is ready for firing.

Firing by means of an exploder is always to be preferred to a battery, but it must be remembered that an exploder cannot be depended on to fire mines in divided circuit. They must be in series.

High Explosives.

Guncotton.

A charge of wet guncotton is detonated by means of the explosion of a dry primer in close contact with it.

The slabs and primers for field service are as follows :—

(*a*). *Slab.*—Weight, 15 ozs. Dimensions, $6'' \times 3'' \times 1\frac{3}{8}''$, with one perforation for the primer. Each slab is in an hermetically sealed copper-tinned case.

(*b*). *Primer.*—Weight, 1 oz. Dimensions, 1·35″ to 1·15″ in diameter by 1·25″ long, with one perforation for the detonator. The primer is conical in form.

A charge is connected up for detonation as follows :—

The fuze (safety alone or safety with instantaneous) is cut to the required length. The end to be ignited is cut on a slant to expose as much of the composition as possible. The end to be inserted in the detonator is cut straight across. The straight cut end is then gently inserted into the open end of No. 8 detonator. This end of the detonator is then pinched to make it grip on the fuze and so prevent its being withdrawn.

The primer having been tested to receive a detonator is placed in the recess in one of the slabs of the charge, and the small end of the detonator is gently inserted into it so as to fill the entire length of the hole. (If the hole is too large, a piece of paper or grass must be wrapped round the detonator to make it fit tightly ; if too small it must be enlarged with a rectifier or piece of wood, but

not with the detonator). The tins are used as issued; it is not necessary to remove the guncotton from them.

THE CHARGE MUST BE IN CLOSE CONTACT WITH THE OBJECT TO BE DEMOLISHED, AND EACH TIN MUST BE IN CONTACT WITH THOSE NEXT IT.

The charge must be extended across the whole length of the object to be cut. One detonator is sufficient for a continuous guncotton charge.

The following number of pounds of guncotton (including primers) are carried:—

Field Squadron, R.E...	920
Field Co., R.E. ..	570
Cavalry Regiment ..	105

Ammonal.

Another explosive which may be met with is ammonal. This is hygroscopic, and must be kept in air-tight cases. The greased paper cartridges (supplied in the 5-lb. tins) will suffice for temporary purposes. It will often be obtained in tins containing 1lb. and measuring $6'' \times 3'' \times 1\frac{1}{2}''$. Each of these tins has a tube at one end for the detonator. Ammonal should be fired with a No. 8 detonator or No. 8 commercial cap.

These tins should be used as issued. Ammonal is not so strong as guncotton. An addition of 75 per cent. should be made to the charges given by the guncotton formulæ.

Dynamite.

This is the generic name for a number of nitro-glycerine explosives. The ordinary dynamite of commerce is a mixture of 75 parts of nitro-glycerine with 25 parts of a peculiar clay. The colour is buff or reddish brown; it is plastic in nature and generally made up in small cartridges, wrapped in parchment. Its power is somewhat less than guncotton, but, for all practical purposes, the guncotton formulæ can be used.

It freezes at about 40° and is then susceptible of explosion by ignition. Until thawed, it is practically useless as a blasting agent. To thaw dynamite is a work of

care, for there is always liability to explode if heated up to 360°. It should never be warmed on or before stoves and fireplaces, but thawed in an empty water-tight case, which should be placed in hot water at 130° F.

The service detonators will explode dynamite, but copper caps are used in civil life and are cheaper. The method of use of these is much the same as with the service detonator. For use under water, care should be taken to have the upper end of the cap water-tight, with grease, tar, etc. A cartridge is opened at one end, and the cap, with fuze in it, is pushed in so as to leave about one-third of the copper tube exposed. The cap is then tied round in that position. When used in rock blasting, the cartridges are inserted into the blast-hole and pressed home with a wooden rammer. Iron should not be used, nor any unnecessary force. Over the charge the cartridge, with cap and fuze, is inserted, and loose sand is poured in as tamping.

Cordite.

Cordite for demolitions may be obtained from gun cartridges. Cordite consists of nitro-glycerine and gun-cotton incorporated and gelatinized by the aid of a solvent, a small proportion of a mineral hydro-carbon being introduced.

For demolition purposes cordite is uncertain in its action, and should only be used when no better explosive is available. The small sizes are fairly reliable.

It is fired similarly to guncotton ; a primer of guncotton or other high explosives must always be used.

A cordite charge should always be bound up tightly and fixed firmly against the object of demolition. It should in most cases be tamped, but this is not necessary when used against metallic structures, *e.g.*, rails and girders. No portion of a cordite charge should be more than 12″ from a primer, since the rate of communicating demolition is slow.

An untamped charge must be well protected from possible sparks from the fuze, since cordite ignites very easily.

Where good contact can be obtained, the power of cordite is equal to guncotton, otherwise a cordite charge should be increased by about 25 per cent.

Demolition.

Deliberate Demolition.

In deliberate demolitions a partial failure is not of serious consequence, economy of material being important. In hasty demolitions economy of material is a secondary consideration, and no failure can be permissible.

In buildings with very thick walls it is convenient to sink shafts and lodge charges under the foundations, unless the soil be harder than the walls. In this case the charges should be lodged in the wall by means of small galleries. The resistance of ordinary masonry may be roughly taken as $1\frac{1}{2}$ times earth.

In buildings with walls less than 4′ thick, a series of charges should be laid all along the wall, inside if possible, and well tamped. If the charges be sunk a little way into the wall, so much the better. Charges of powder of $\frac{1}{8}$ LLR^3, placed in the centre of a wall at 2-lined intervals, will produce complete, but moderate, demolition. When the saving of powder is an object, it may be worth while to cut away the lower part of the walls, leaving piers (in which holes have been prepared) to be blown up afterwards. In all cases the holes should be made at an angle of 45° downwards.

In destroying masonry bridges of a single arch, attack the haunches, throwing the excavated earth above the crown of the arch. Or else put the charge at the crown, and set men to dig out the earth over the haunches, piling it over the charge. The arch will tend to fall by this means, even though the charge may be otherwise insufficient. In a bridge with high piers, place charges as close as possible to the base of a pier, as its fall will bring down two arches. A series of charges at 2-lined intervals should be placed and fired simultaneously. When the piers are broad and thick it is better (because less uncertain) to attack the arches than the piers, either by a

single charge in the centre, or a series of charges in a line across the arch.

The distance in plan of the charge from the side of the bridge should = 2 LLR. The depth of the shaft should be at least 2, and better 3 times LLR.

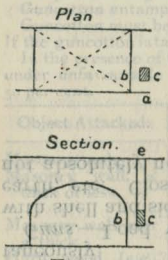


FIG. 4.

Thus in *Fig.* 4, *ca* should = 2*cb*, and *ce* = 3*cb*. Two or more charges across the haunch are better than one in the centre. These should not be distant from each other more than 2 LLR.

Total charge of powder in lbs. = $\frac{2}{3}$ LLR^2 × B, either in a single mass or in a line of charges. LLR = line of least resistance in feet, measured through the arch, B = breadth of the bridge in feet.

A girder bridge, with masonry piers, is most effectively destroyed by blowing up the piers, provided they are not too thick, for the girders in falling will be so damaged as to be useless. With suspension bridges the most efficient destruction is to cut the suspension chains.

In tunnels, the easiest parts to attack are the side walls, but the most serious injury is done by explosion from the crown. The charges in every case should be much larger than the calculated amount, so as to bring down not only the tunnel lining, but also much of the surrounding rock, etc.

Hasty Demolition.

Masonry or Brick Bridges.—Attack pier where thinnest; if possible, cut groove, or else tie charge to a board and fix it against pier.

With thick piers attack haunches. Dig trench to back of arch ring at each haunch and lay charge. If time is short, attack the crown similarly.

Houses (weakly built).—Put charge in centre of each room or hearth of fireplaces, fire simultaneously. Mud huts up to 18′ square with walls 2′ thick at bottom, 4lbs. guncotton in one corner. Four-room cottage, 6 to 12lbs.

Towers (as on N.W. Frontier, India).—Place charge in hole 2 to 3′ deep in centre of floor; tamp well. Charge in lbs. equals inside diameter or side in feet plus 5.

Iron or Steel Bridges.—Use guncotton. Attack main girders near abutment.

For hasty demolition of *standard gauge* railway girder bridges, 20 to 80′ span, where there is not time to measure the section of the girder :—

$$C = \frac{L^2}{15D}, \text{ where } C = \text{charge of guncotton in slabs (15 oz.)},$$

including 50 per cent. extra for presence of enemy, for one girder of single line of standard railway, L = length of girder in feet, D = total depth of girder in feet. Where one girder bears whole load of a line of railway, *e.g.*, two girders carrying a double line, or a centre girder carrying half of two single lines, amount given by formula should be doubled.

For all girders, divide total charge proportionately to area of upper and lower halves of section, and place in diagonally opposite angles of girder formed by junction of web with top and bottom flanges. Spaces between rivet heads to be packed with clay. Fire charges simultaneously.

Guns.—Load with a shell, pack in charge in contact with shell and sides of chamber. Tamp charge with sods, earth, etc. Close breech as much as possible. (Shell is not absolutely necessary).

Table of Charges for Hasty Demolitions.

Charges are in lbs. ; B and T are in feet ; t is in inches. B is length of breach to be made. T or t is thickness of object to be demolished.

Gunpowder roughly tamped with sandbags.

Guncotton untamped.

Guncotton must be equal in length to the breach which is to be made. If the guncotton is tamped, the charges may be reduced to about one-half.

In the presence of the enemy, charges may be placed hurriedly, and so under unfavourable conditions, and should therefore be increased by 50 per cent.

Object Attacked.	Gunpowder.	Guncotton.	Remarks.
Masonry arch	$\frac{3}{20}$ B.T.^{2}....	$\frac{3}{4}$ B.T.^{2}....	Gives charge in lbs.
Masonry wall, 2′ thick or less.	$\frac{3}{20}$ B.T.^{2}....	2lbs. per foot-run.	The length of breach B should not be less than the height of the wall to be brought down.
Masonry wall over 2′ thick.	$\frac{3}{20}$ B.T.^{2}....	$\frac{1}{2}$ B.T.^{2}....	
Hard wood (*e.g.*, teak, oak, elm), in any form, whether stockade, palisade, single timbers, trees, etc.	40 to 100 lbs. for stockade	3 B.T.^{2}....	In a concentrated charge, or, for trees not over 12″ diameter, in a necklace.
		$\frac{3}{5}$ T.^{3}.	In auger holes. When the timber is not perfectly round, T=the smaller axis.
Soft wood	—	—	Half the charges for hard wood.
Breastwork of horizontal baulks, or earth between timbers up to 3′6″ thick.	60 to 80 lbs. per 5′.	4lbs. per foot.	Baulks simply piled on one another and supported by verticals, or dogged together.
Heavy rail stockade	—	7lbs. per foot.	
Fort gate	200lbs. ...	50lbs.	One charge.
Iron or steel plate	—	$\frac{3}{4}$ B.t^2. ...	t is in inches.
Guns, 3″ to 6″	—	—	For a 3″ gun use 2lbs., and double the charge for every inch increase in calibre.
Steel wire cable ...	—	1 slab	Up to 5″ circumference. Above 5″ $\frac{C^2}{24}$, C being circumference in inches.
First-class rail	—	1 slab	Charge fastened against web near a a chair (if used).
Tunnels	$\frac{2}{3}$ T.^{3}.	—	T = total distance from surface of lining to the charge.

For emergency purposes B.T.^{2} is effective with all classes of masonry and 2B.t^2 for all steel work. For all practical purposes the formulæ for guncotton in the Table may be taken on an emergency to apply to other high explosives than those described previously. But, when an explosive of unknown strength has to be used, experiments should be made to ascertain its strength as soon as possible, in order to avoid failure or waste of explosive.

Thatch may be easily fired by placing one or two dry discs of guncotton among it and igniting the discs. A piece of paper wrapped round the discs and lighted will ignite it. In burning villages it is useful to make some holes in the roofs to increase the draught.

Demolition of a Line of Railway.

This may be done, without explosives, by burning sleepers, removing or twisting the rails in a fire, taking away switches, water tanks, telegraphic and workshop apparatus, as well as rolling stock. With explosives the most rapid injury can be effected.

By using trollies, loaded with slabs of guncotton, great lengths of railways can be destroyed. The slabs will be made up in charges with primers, and there will be also detonators, safety fuze, quick match, and wire all ready. A party of eight men can be employed; two push the trolly, two sit on the trolly, fix the detonators on the slabs, prepare binding wire, and hand out the charges to two other men, who place them against the rail. The remaining two men follow 150 yards in rear and light the fuzes as they pass.

Demolition of a Line of Telegraph.

To destroy a line of wooden poles, attack those that have stays. Get a rope attached to the top of a pole and let the pole be partly cut through about 4′ from the ground. All hands should then haul on (standing well clear) except one man, who cuts through the stay with file or pincers. The adjacent poles may also be partially cut, with their stays. Iron poles should be

partially cut, with their stays. Iron poles should be

destroyed with guncotton. The wires should then be cut at each end and twisted up, and the insulators broken.

If there are skilled telegraphists with the party, faults may be put on the lines, either by disconnections, leaks, or contacts. The easiest way is to twist a piece of wire round several of the telegraph wires so as to connect them ; or they may be connected to the earth wires which run down the poles. Another plan is to cut the wire and replace it with a piece of low conducting power, but of the same gauge, so as not to be detected by the eye.

SECTION VI.

WATER SUPPLY.

In standing camps 5 gallons per man and 10 per horse or camel for all purposes are sufficient. For permanent hospitals 40 gallons per man.

Minimum daily quantity required, 1 gallon per man for all purposes. Minimum for drinking purposes, transport animals 6 gallons, sheep and pigs 1 gallon.

In regular standing camps, *with a piped water supply*, 5 gallons per man and 10 per horse is inadequate. Once a piped supply is admitted, and where the men have time to bathe, cook, and use water exactly as in barracks, experience shows that even with good discipline 15 gallons per head is not an excessive allowance.

One gallon water at 62° Fahr.= 10lbs.; 1 cubic foot= 62·425lbs.= 6¼ gallons. The capacity of a gallon= 1′ sq. by 2″ deep, or 1′ diam. by 2½″ deep. One cubic mètre= 220·09 gallons.

A pipe 3′ long holds about as many lbs. of cold water as the diameter squared (in inches).

For calculating pressure due to head, let P= pressure in lbs. per square inch, H= head of water in feet, V= theoretical velocity in feet per second, g= 32·2, then $P = H \times \cdot 4335$, $H = P \times 2 \cdot 307$, $V = \sqrt{2gH}$ or $= \sqrt{H \times 8}$, $H = \cdot 0155V^2$.

The *rainfall* in different parts of a given country is generally greatest in those districts which lie towards the quarter whence the prevailing winds blow. Upon a given mountain ridge the reverse is the case, the greatest rainfall, *as a rule*, taking place on the leeward side, as regards prevailing winds. Rainfall is greater in hilly than in flat districts.

Rain water collected at a distance from towns is more

nearly pure than water from any other source. Freezing water has nearly the same effect as distillation, so frozen sea water is generally fresh.

A *wholesome water* should be free from colour, taste, and smell. Peaty water of a light brown colour is not objectionable. When exposed in a glass vessel, water should leave no sediment, nor should its steam give off any smell. To test for colour, put the water in a deep vessel, put a silver coin at the bottom, and look down vertically. To test for smell, boil in a kettle and smell the steam.

Running water is generally safe, because offensive organic matter becomes combined with the oxygen of the air, and is rendered harmless. For potable water streams of moderate declivity or gentle (but not too slight) fall are superior to streams of high declivity and, other things being equal, those streams which are most completely broken up into alternating pools and rapids are preferable to streams whose profiles are more uniform. Every stream, however affected by sewage, is rendered much less foul, and is often practically pure, after running a few miles through an open country.

Foreign substances exist in water in various proportions, some lakes having only 2 grains per gallon, while sea water (Atlantic Ocean) has 2,688. Clear river water has on an average 25 and well water 30 grains. Foreign substances are not necessarily injurious. Spring waters are more likely to be wholesome than river or lake.

The following are *sources of contamination* :—In rivers, heavy floods, the influx of salt or marsh water, and town sewage of all sorts. Ponds become impure from the putrefaction of vegetable matter, tanks from want of periodical cleaning, surface wells from sewage soaking in, or from subsoil water charged with refuse, or from surface water carrying in impurities.

A well in porous strata drains a volume of earth round it in the shape of an inverted cone, the diameter of the base being often two or three times the depth of the well. The water from deep wells has generally much mineral matter, and is hard, but wholesome. Sea water can be distilled in small quantities (avoiding the use of lead

piping), or its steam may be collected in wool, etc. Snow and ice, if not melted, are no substitutes for drinking water.

The rocks that supply water most freely from wells are :—Chalk, green sand, new red sandstone, magnesian limestone, and some of the carboniferous sandstones.

Searching for Water.

Surface springs may be looked for in depressions below the general level, where the earth is moist, or herbage unusually green, where animals have been scratching, or insects hover, where the thickest mists rise in mornings or evenings.

Near the sea, water can generally be found not far from the surface, but if too close to the sea it is generally brackish.

In hilly countries, the foot of the hills should be searched, or where impervious strata with a downward dip crop out below pervious ones. Water is most likely to be found on the side which has the most extensive watershed, above the contracted portions of valleys, at the junctions of two or more valleys or watercourses, in the beds of dried-up rivers, etc.

Tube wells are very useful for search, as they can be driven and taken up in case of no supply. By driving these wells near small ponds animals can be watered without going into the pond and fouling it.

Where animals drink, whether from troughs or streams, have the ground paved or metalled, or at least covered with brushwood.

Gauging the Supply.—Pump out the well, and then note how long it takes to get a given quantity of water into it. The supply of small streams can be ascertained by fixing a waste board, with a notch cut in it, with horizontal sill. Then if d = depth of water flowing over the sill in feet, a = area in feet, *i.e.*, depth of water × width of orifice in feet, $\frac{2}{3} \sqrt{d} \times a \times 5{\cdot}4$ = cubic feet per second flowing over.

The depth should be measured from the top of the sill to the level of the surface of the water where it is not affected by the overfall.

This is generally ensured by driving a stake 3′ behind the weir, with its top level with the bottom of notch. The depth of water flowing can be measured by a rule held on the summit. There must be a clear outfall below the weir, so that there is no back water.

Another plan is to make a weir across, and note the time that the water flowing over, through a shoot, takes to fill a vessel of known size. When the banks are too low to admit of a weir, observe surface velocity V in feet per second by floats allowed to travel as far as possible where current is regular. In observing the passage of floats, several should be used. They should be placed at various sections of the chosen length of the channel, so that the mean velocity may be determined with the greater accuracy. In the absence of a watch, the oscillations of a string 39″ long with a weight at the end should be observed. Each of such oscillations is exactly one second. Take mean section S in cubic feet from as many sections as possible. Then the discharge Q in cubic feet per second = ·8 VS.

To gauge a small stream, make a dam, get a lot of vessels of known capacity, and drive a stake into the pool formed by the dam with a mark on it a little below highest water level. Bale out till the water is a little below the mark, then let it rise to the mark and note the time. Bale out again and keep on baling for about an hour, noting the number of bucketfuls. Then let the water rise again to the mark and note the time when it gets there. If C = No. of cubic feet baled out, T = difference between time in minutes, then

$$\frac{C}{T} = \text{No. of cubic feet per minute discharge in the stream.}$$

With running water, *dams* may be made to store the water, the overflow being received into shoots of V shape. The best way to make a dam is to get large sandbags or sacks, fill them partially with clay, and ram them tight. Small dams can be made with sods and earth when the pressure is slight. Stones should *never* be put in earthen

dams, as it is impossible to get a water-tight joint between the stones and earth. The overflow should, if possible, go round through the solid banks. If wooden shoots be used, make the tip of the shoot the lowest point along the top of the dam. Tarpaulins can be used in small dams, and the shoots may be lined with tin (old biscuit tins are most useful).

Puddling.

The silt or natural deposit of tidal rivers is good, but stiff, strong plastic clay does not answer. To make puddle, a spade made like a cheese scoop should be used, and the man who works it should either have bare legs or wear mud boots, as he *must* work the stuff up with his feet. The natural ground at the bottom of the trench which it is proposed to puddle should be loosened, but not thrown out. Then water should be plentifully poured on it, and the workmen, walking up and down and working with their scoops, should reduce the natural soil into slush. Then the puddling clay is brought in barrows, thrown into the trench, and incorporated with the slush; the more the stuff is worked by the feet and scoop the better will the puddle be. The layers of puddle should never be more than 9″ thick without being trodden and worked. The stuff should be kept so wet that the feet sink in 8″ or 9″ at each step. In making a dam across a stream, the best way is to divert the stream, and make the dam in the required site with an inner face of puddle and outer backing of earth, or whatever material is available, then, when the whole is complete, turn the stream back again. It may be necessary in some cases to make large reservoirs on porous soil, in which case the whole of the bottom must be puddled, and puddle faces must rise in the banks above the water level. The interior faces of large dams should be revetted.

In springs, it is a good plan to open the spring head and put a cask or brushwood cylinder down for a lining. If the springs overflow, construct deep, narrow tanks, arched over, and lead the water into them. The overflow from one tank should be led into another.

Purifying Water.

Boiling removes CO_2, all the carbonate of lime (except two grains per gallon), a little iron and H_2S, partly decomposes organic matter, and destroys vitality of germs.

Alum to the extent of 5 grains per gallon added 24 hours before use precipitates all suspended matter, and is not hurtful. A lump the size of a walnut slowly stirred in a bucket of water will cause all matter in suspension to be precipitated in about 10 minutes.

Tea leaves after use may with advantage be put into drinking water, as the tannin helps to remove organic matter.

Filtration through clear sand and gravel is one of the best means of purification. Use 1′ thickness of gravel and 3′ thickness of sand, increasing in fineness from bottom to top. The water, which should be gently introduced at the highest level of the sand, should pass through it at the rate of 4″ an hour, which gives 50 gallons in 24 hours through each square foot of filter bed. To attain this rate the head of water should not exceed about 3′. The filtrate from fresh sand should be allowed to flow to waste for awhile. After a time the sand, etc., requires removal and cleaning. The sand must be free from all contamination. To ensure this it should be roasted; neglect of this precaution has actually lead to a widespread and very fatal epidemic of cholera.

Another method of purifying water is to pass it through a coil of pipes inside a tank of boiling water, the pipe then passing through a second tank of cold water. The object of the first tank is to raise the heat above boiling point, and thus destroy living organisms, the object of the second tank is to cool the water so as to be drinkable.

In large filtering operations there should be two tanks connected by a narrow channel with the filtering material. The upper tank is to allow the water to settle and deposit any suspended matter.

To *make charcoal*, dig a pit 5′ diameter, 3′ deep, and keep a fire in it of pieces of small wood. When this is

burning fiercely, put in sufficient wood to raise the whole 1 foot above ground, then shovel back the earth over the burning mass. All the wood should be about the same size. Leave for 24 hours, when the pit will be found nearly full of charcoal.

Purification of Water.

Any natural inorganic (*i.e.*, mineral) impurities in water carry their own warning; for small quantities render it unpalatable or noticeably "hard" long before the quantity is enough to make it dangerous to drink. An exception is common salt. Any considerable excess of this over the normal, even though the water is not in the least brackish to the taste, is an almost certain sign of sewage contamination. Such an excess can only be determined by analysis. Lead and zinc are dangerous, but artificial, poisons, usually introduced by using unsuitable piping.

Organic foreign matter in water is dangerous (*i.e.*, animal and vegetable matter including "microbes," living, dead or decomposing) not because it is all dangerous in itself, but because pathogenic (disease-bearing) bacteria and harmless matter, some of which is their food, are inextricably mixed up. Organic matter must obviously be in the form of suspended solids (some of them microscopical in size) in contrast to inorganic matter (minerals) which may be suspended or dissolved. The quantity usually met with is small (hopelessly turbid waters excepted), but it is the power to do evil that is the danger. One method of purification therefore is to convert organic matter, the harmless with the harmful, into stable minerals; the resulting quantity of them being negligible in amount. Another method is to sterilize (*i.e.*, kill) the active bacteria, the harmless with the pathogenic; the resulting inert organic matter being again negligible in amount. A third method, when the suspended matter is considerable (*i.e.*, when the water is turbid), is to strain out the solids, or by giving the water rest to let them sink in the form of sediment, and then remove them. These methods may be employed separately or combined;

thus a turbid water may first be strained, then filtered to get further purification, and then boiled. Sterile water is the safest, but if *unprotected and again contaminated* organisms multiply in it unchecked with incredible rapidity.

The first method is carried out in filters (true filters from the water-engineers' point of view are not merely strainers as is often supposed) which are designed to give the best surroundings for nitrifying organisms to work in. These bacteria, if sufficient oxygen is present, mineralize 98 per cent. of the organic matter in the water as it passes through. Filter beds of this nature require careful construction and working, as they are really nothing but bacteria beds; and they are useless or in some cases positively harmful if not worked in a proper way. Their efficiency can only be tested by bacteriological tests.

Filtration.

Filtration by filter beds, in the real sense, cannot be carried out in temporary schemes, but can be in large semi-permanent schemes; or mechanical filters such as the Jewell or Candy may be employed.

The action of candle filters such as the Pasteur Chamberland and Beckfield is, in principle, similar to that of filter beds, the fineness of the filtering medium making up for its smaller thickness and the whole process being on a much smaller scale.

Filtration by candle filters may be positively dangerous unless it is clearly understood that it is not only straining action that takes place. When clean and in good order, a candle filter both arrests and nitrifies organic matter, good or bad, but a day or two's use may result in such a multiplication of bacteria, especially the pathogenic forms, that nitrification may be entirely stopped and the advantages of any straining that takes place may be more than neutralized. The usual regulations as to cleaning such filters are therefore absolutely necessary, and frequent cleaning cannot be dispensed with even though water passes easily through the filter or becomes visibly

clearer. The efficiency of a filter cannot be properly judged by physical tests alone.

When using a candle filter it is an advantage to remove solids beforehand as much as possible by straining or settlement. It is not so much that the efficiency of the filter is increased as that coarser work is taken from it, which it should not be called upon to do.

Sterilization.

Sterilization, the second method of purification mentioned, is quite possible in semi-permanent or even temporary schemes, but it has strict limitations. As there are strong prejudices against chemical sterilization apart from the difficulty of ensuring proper regulation of the amount of chemicals to be added, sterilization by heat is usually the only practicable method. Water cannot be heated in bulk because it is difficult to cool it within a reasonable time. Another objection to the storing of large quantities of sterilized water is that, as already mentioned, it is extremely susceptible to contamination. Therefore where any appreciable store of sterilized water is made it is essential that it should be *protected, e.g.*, buckets, etc., should never be dipped into sterilized water. Sterilization is the best method when operations are only on the " tea-kettle " scale, that is to say, when each small group of persons sterilizes their own supply and uses it immediately. Water-sterilizing apparatus will therefore be on a small scale, and engineering arrangements present no difficulty. The main point to remember has been already noted.

There remains the third method of purification to consider, *the bodily removal of suspended matter*. There are several obvious ways of doing this. For very small supplies cloth may be used. It is more usual to pass the water through a few feet of graduated sand and gravel, which may be conveniently placed in barrels. This is mechanical straining only, not real filtration.

Exactly the same result can be achieved if the water is allowed to rest in settling basins so that suspended matter

can settle. In permanent works the most efficient depth is between 10′ and 16′, but rest in *any* form of basin does the water good. Water that is practically motionless (and provided the turbidity is not due to extremely fine divided clay) will settle 75 per cent. of its solids in the first 24 hours, and 90 per cent. within three days. The water drawn off quietly at the top is then almost pure.

Sedimentation can be hastened by the addition of a little alum ; care must be taken not to use too much.

In both these methods it must be remembered that separation only is achieved, and cleaning of the sand and gravel, or clearance of the sediment as the case may be is necessary at intervals : otherwise re-contamination may occur. The latter method is at least as effective as the former and easily arranged, but it entails a sufficient reserve supply (to enable rest to be given) and more room. The straining filter method is open to the objection that the sand may be kept too long and become highly contaminated.

From what has been said it is clear that all that can usually be attempted are some simple arrangements, (i.) for sterilizing water by heating it to 180° Fahr. and ensuring its protection during distribution, (ii.) for straining water, due attention being paid to keeping the straining material clean, and (iii.) for settling water to separate the sediment.

Distribution of Water.

In distributing water, be careful to distinguish that which has been filtered from other water. The former should be collected in separate troughs, and should be marked (on a notice board) " For drinking and cooking only." Troughs for animals should be distinct from those to be used by troops.

Water-troughs of a very light and portable description can be made of sail-canvas. These should have a number of eyelet holes round the edges (not necessarily bound with metal) to fasten to loops or hooks whence the trough should be suspended. This may be done by putting upright stakes about 2½′ above the ground, fastening a cross-

bar, and letting the trough hang either by S-shaped hooks or by lashings. If the canvas sides touch the stakes the water will leak. Canvas water-troughs 6′ long are articles of store and are described as Tanks Waterproof, 2,300 gallons and 600 gallons. Wooden troughs are suitable for standing camps, but not for mobile columns.

If possible, arrange to water all the horses in a camp in one hour. There should be one watering-place for every 1,000 horses.

Pave and drain the vicinity of troughs for a distance of at least 10′ and have separate approaches and exits. Horses drink about 1½ gallons at a time, should be allowed 5 minutes, and each occupies laterally 4′.

To carry water, *masaks* and *pakáls* are used. The former is the skin of a goat, and can be carried by one man. The latter is a skin vessel holding about 20 gallons; two of them form a mule or bullock load when full. Canvas bags to hold a gallon are sometimes used.

If it be required to make canvas waterproof, the following is a recipe:—1½lbs. hard yellow soap cut into thin shreds, and boiled in 6 pints of water till well dissolved. Mix in by degrees, when the solution is hot, 20lbs. of English spruce ground yellow ochre. Add 2lbs. of patent driers, and 2½ gallons of *best* boiled linseed oil.

The seams of all canvas bags and troughs should be double and close stitched.

Raising Water.

Without Pumps.—For deep wells, have a bucket and windlass which can be worked by hand or horse-power.

Shallower wells may be treated with a lever having a bucket at one end attached by a rope, and a counterpoise at the other. A leather bag called a *charsa* is much used in India. It works over a wheel at the edge of the well, and is hauled up by animals walking down a slope.

Persian wheels are a method whereby an endless chain of buckets passes round a vertical wheel above the well,

and is driven by an animal going round a horizontal wheel geared to the axis of the other.

If syphons are used with flexible hose, the total amount of lift must not exceed 30′.

Pumps.—The Mk. I. service *lift and force pump* (also called the 4″ ship's fire-engine pump) weighs 140lbs. Two men can work it, and force water to a height of 60′ at 720 gallons per hour. The delivery hose 2″, and suction 2½″ diameter. Mks. II. and IV. differ in weight and other details from Mk. I., but are generally similar.

The service *tripod pump* is for lifting only. It weighs 103lbs., has a reducing socket for tube wells, and is adapted for use with the service water-carts.

The *Bastier* pump is for vertical lifts only. It consists of an endless chain passing round a wheel vertically above the centre of the well, and also passing through iron tubing let down into the water. This chain has at intervals india-rubber discs which fit inside the iron tubing, and, as the wheel revolves, lift water in the tubing. The principle is exactly that of a Persian wheel, only instead of buckets there is the iron tubing and india-rubber discs. At the bottom of the tubing, which is in 8′ lengths, bolted with flanges, there is a bell mouthpiece. Care must be taken that this is well under the surface of the water, but not too near the bottom.

The motive power is either hand (for the smaller diameter), steam, or animals, as in Persian wheels.

This pump is simple, light to carry, and not liable to get out of order. Each pump is fitted with special gear for use with animals, *i.e.*, horizontal bevel wheels, pinion, shafts, cast-iron bedplate and frame, etc.

These pumps may be supplied either with 2½″ tubes or 6″. The total weight of stores for one 2½″ pump for 60′ lift is 881½lbs., and the horse gear 647lbs. additional.

There are various other pumps which may be utilized with steam power for raising water from wells, such as *pulsometers* and *centrifugals*, but the cases in which such would be required with an army in the field are exceptional.

Norton's Tube Wells.

These are used for obtaining water from water-bearing strata at moderate depths. If the water rises in the tube to within 28′ of the surface, the ordinary lift pump can be used. The tube has a solid iron and steeled point; it admits water through perforations just above this point, and the whole is driven by a *monkey* hitting a clamp screwed on to the tube. The condition upon which these wells are effective is that there shall be a free flow of water through the perforations into the tube. In porous soils the flow is free, but in tenacious clays the holes get sealed, and no water gets in. It cannot be driven through rock. These wells have been driven in England 117′ through chalk and gravel at a rate of 12′ an hour, in softer ground at 20′ an hour. The service tubes are about $1\frac{3}{4}$″ external diameter, and in lengths of 3′ to 11′, connected by collars. The joints should be made water-tight with white lead.

To use the tube well, select a position, make a hole in the ground with a crowbar, fix the clamp, monkey, and pulley-bar to the tube, and insert it into the hole. The clamp should be fastened 18″ to 2′ above ground. The monkey is raised by two men standing opposite one another and pulling at the same angle. The tube must be kept perfectly vertical, and must not be swayed about when driven (the men must work together). A third man steadies the monkey.

The clamp must not move on the tube; its bolts must be tightened up at the least appearance of slipping. When it has been driven down to the ground, the monkey is raised, and the clamp shifted, and so on as before, till it is required to screw on a new length. The collar is first screwed to the portion in the ground, then the next length into the collar. Soon after a new length has been added, the upper length should be turned round a little with the pipe tongs to tighten the joints, which have a tendency to become loose from the jar. Be careful, when a water stratum is reached, not to drive through it.

From time to time, and always before screwing on a

new length, sound with a small lead to see what water, if any, is coming in, and the character of the earth penetrated.

When water does come it is generally thick at first, but after pumping awhile it becomes clearer.

If the bottom of the pipe is choked, cleaning pipes $\frac{1}{2}''$ in diameter have to be used. These have to be lowered very carefully, so as not to drop them. When these have reached the bottom, the pump is attached by means of a reducing socket; the lower end of the cleaning pipe is raised and held about an inch above the accumulation by means of the tongs, then water is poured down the well outside the cleaning pipe, and being then pumped up through the cleaning pipe brings away the upper portion of the accumulation. This is repeated until the whole obstruction is removed.

The actual work of penetration is done by the first tube with its point, leaving the tubes that follow practically no resistance to overcome.

These wells have been made of a larger diameter, driven by a weight delivering a blow inside the tube immediately above the point. A short sheers may be arranged so that the head serves as a guide for the tube, and thence two uprights rise carrying a pulley or block, over which the rope for the weight travels.

For large supplies of water, several tube wells may be sunk close to each other, 20 to 50 yards apart. The tops of all may be connected by bends and junctions to one main, and thus pumped through one pump.

To *draw the tube well* when no longer required, the following methods are employed:—(1). Place the monkey on the tube lower end upwards, and screw on the clamp face downwards about 1 foot above it. The monkey is then raised sharply, and gradually forces up the tube. (2). Pass a short length of chain twice round the tube close to the ground, with the end passed through a large ring at the other end. Lift by means of a crowbar or other lever acting on any convenient fulcrum and passing through a movable stoppering link made to grip any link desired. This is a quick and simple way, but not always so effective.

These tube wells are useful for testing ground to ascertain how deep water lies beneath the surface, and testing quality and quantity before going to the labour of making ordinary wells.

Ordinary Well-Sinking.

Wells up to 8′ diameter may in some stiff soils be sunk to a great depth without any lining, but it is, of course, more risky as the diameter increases. On the Indian frontier 6′ wells 100′ deep are not uncommon. It is customary in some places to put a steining for the first 20′ or so from the surface. If the strata are varied, it is better to put some sort of lining throughout, on account of irregularity of pressure. In any case a framework is desirable on the surface of the ground at the top. This may be simply a square of timber, but it is better with two squares of equal size, as in *Fig.* 1, forming an octagon, the inscribed circle of which is the outer edge of the steining. The tops of the timbers should be flush with the ground. This framework prevents the ground at the edge from breaking away during construction, and acts as a foundation for the gear for raising the excavated stuff, and afterwards the water.

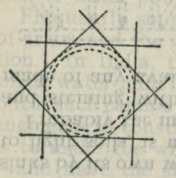


Fig. 1.

There should be a good stock of buckets, ropes, and other tools, before commencing. Then mark on the ground a circle with diameter 12″ to 18″ larger than the intended internal diameter, then lay the framing so as to touch this circle. The centre of the well when begun should be the base whence all work should be measured.

The *brick steining* for large wells should be 9″, and for small wells 4½″. *Well curbs* should be of oak or elm, 3″ or 4″ thick, either in one layer, fished at the joints with iron plates, or in two layers, breaking joint, bolted together.

To *excavate by underpinning* (*Fig.* 2), first dig to such

a depth as the earth will allow without falling in, lay the curb at the bottom, and build steining to the surface. Then, in the centre of the floor, cut a pit, and insert raking props through notches at the side of the pit. The lower ends of these props abut against a foot-block in the centre of the pit, and the upper ends against the lowest sitting. The pit is then enlarged to the diameter of the shaft, a new curb put in, steining built up, and so on.

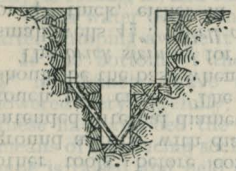


FIG. 2.

To excavate *with drum curbs*, the curb should be made with cutting edges, the soil should be excavated from below, and the steining weighted above. The whole steining sinks by its own weight. This method, which is applicable to light soils, is used for heavy foundations in civil life.

Probably the most useful for military work is excavating and steining with a *cylinder shield* (*Fig.* 3). A shield is made of any available material (sheet-iron, timber, brushwood, etc.) of an external diameter rather less than the internal diameter of the well, so that it may pass freely up and down the shaft. This is suspended from beams at the top of the shaft. As the excavation proceeds, the shield is gradually lowered till the full length of the cylinder is attained, then the curb is put in by *segments*, and the steining built also in segments. The office of the shield is to hold back any earth which may become loose during the excavation. When the segments between the props have been built up to the top, the props can be removed and the steining completed, and the operation repeated in the next division of the well, each division being equal in depth to the length of the cylinder. A convenient length for the cylinder is

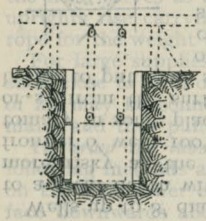


FIG. 3.

about 8′. The workmen in building the steining can make temporary platforms of brick to stand on when necessary, but such platforms cannot be much more than 3′ high, which, with the 5′ up to which a workman can lay bricks, gives 8′.

If the soil is fairly stiff it is not necessary to put curbs in at each section if the bricks are laid in mortar. If there is any danger of impure surface water finding its way into a well, the brickwork may be backed with clay puddle or with concrete.

Applications of Water Power.

It is impossible to do more than indicate a few of the various ways in which labour can be saved by the application of water power.

Frequently supplies are obtained for troops in the form of grain, and the grinding into flour is a serious consideration. In India, there are in almost all the hill districts small water-mills which may be utilized for this purpose, but if such cannot be found, it should be the business of the engineers to construct them. The simplest and best form is to make the wheel horizontal—a rough turbine in fact—and have the stones which grind the corn fastened to the same shaft as the wheel.

If this is not practicable, and vertical wheels, either overshot or undershot, have to be used, the vertical motion must be turned into horizontal by means of bevelled wheels, or some such manner.

Water may be pumped into troughs by its own action. The wheel of a G.S. wagon, furnished with paddles round the circumference, and fixed over a running stream, may, by means of a rope attached at one end to the handle of a pump, and at the other end to a point on the wheel, pump up water from the stream, and has been so used with success.

Canals.

In countries where canals are used for irrigation, there is often a considerable current in them, and, therefore, apart from their value as communication, they may

become of importance in military operations by the control which may be held or lost over large quantities of water. The head works of canals, where there are sluices regulating the influx of water from the parent stream, the escapes at intervals, where by means of sluices water can be turned out of the canal into other channels, become points of military importance, and may have to be secured and controlled by the engineers of an army. Care should be taken, therefore, that all sluice-gates and valves are in working order, and that, if attack is apprehended, protecting earthworks are constructed to defend them.

Both in navigable and irrigation canals, *locks* are often of military importance. These consist of a lock chamber, with head and tail gates at each end. They are emptied and filled, sometimes through sluices in their head and tail gates, but more generally through inlet and outlet passages, with slide valves, round the gates. These passages may be either culverts in the thickness of the masonry, or iron pipes. The gates are opened and shut either by means of *balance bars*, which act as a counterpoise and lever, or by chains and windlasses. In any case the vulnerable points of a canal lock are the gates and the valves. It may sometimes be necessary to protect these points against artillery fire.

Table showing in feet the Head of Water consumed by Friction in each 100′ length of Pipe.

Delivery. Gallons per Minute.	Internal Diameter of Pipes in Inches.											
	½	¾	1	1¼	1½	1¾	2	2½	3	3½	4	5	6
1	9·181	1·171	0·269	0·087	0·034	0·016	0·008						
2	36·724	4·684	1·076	0·347	0·137	0·062	0·031						
3	82·629	10·541	2·421	0·780	0·308	0·140	0·071						
4	146·896	18·719	4·304	1·387	0·548	0·249	0·125						
5	229·525	29·281	6·724	2·217	0·856	0·389	0·196	0·062					
6		42·165	9·683	3·120	1·233	0·560	0·282	0·089					
7		57·391	13·180	4·247	1·678	0·763	0·384	0·121					
8		74·959	17·214	5·547	2·191	0.996	0·502	0·159					
9		94·870	21·787	7·020	2·773	1·261	0·635	0·201					
10		117·124	26·898	8·667	3·424	1·557	0·784	0·248	0·064				
11			32·546	10·487	4·143	1·884	0·949	0·300	0·077				
12			38·732	12·480	4·930	2·239	1·130	0·357	0·092				
13			45·457	14·647	5·786	2·631	1·326	0·419	0·107				
14			52·719	16·987	6·711	3·051	1·538	0·486	0·125				
15			60·520	19·500	7·704	3·503	1·765	0·558	0·143	0·065			
16			68·858	22·187	8·765	3·985	2·008	0·635	0·163	0·074			
18			87·148	28·081	11·094	5·044	2·542	0·803	0·206	0·093			
20			107·590	34·668	13·696	6·227	3·138	0·992	0·254	0·115	0·058		
22				41·948	16·572	7·535	3·797	1·200	0·308	0·139	0·070		
24				49·921	19·722	8·967	4·519	1·428	0·366	0·166	0·083		
26				58·588	23·146	10·524	5·303	1·676	0·430	0·195	0·098		
28				67·948	26·844	12·206	6·150	1·943	0·499	0·226	0·113		
30				78·002	30·816	14·012	7·060	2·231	0·572	0·259	0·130	0·041	
35				106·169	41·944	19·074	9·610	3·037	0·779	0·353	0·176	0·056	
40					54·784	24·910	12·552	3·966	1·018	0·461	0·231	0·073	
45					69·336	31·526	15·886	5·020	1·288	0·583	0·293	0·093	
50					85·599	38·921	19·613	6·197	1·593	0·720	0·361	0·114	0·044

Pipe Calculations.—*Cont.*

Table showing in feet the Head of Water consumed by Friction in each 100′ length of Pipe.

Delivery. Gallons per Minute.	Internal Diameter of Pipes in Inches.											
	1¾	2	2½	3	3½	4	5	6	7	8	9	10
60	56·046	28·242	8·924	2·290	1·037	0·520	0·165	0·064				
70	76·286	38·441	12·147	3·117	1·411	0·708	0·224	0·087				
80		50·209	15·865	4·071	1·843	0·927	0·293	0·114				
90		63·545	20·079	5·152	2·333	1·170	0·371	0·144				
100		78·451	24·789	6·361	2·880	1·445	0·458	0·178	0·080			
110			29·994	7·697	3·485	1·748	0·554	0·215	0·097			
120			35·696	9·160	4·147	2·080	0·660	0·256	0·115			
130			41·893	10·750	4·867	2·442	0·774	0·301	0·136			
140			48·586	12·467	5·644	2·832	0·898	0·349	0·157			
150			55·775	14·312	6·480	3·251	1·031	0·401	0·180	0·090		
160				16·284	7·372	3·698	1·173	0·456	0·205	0·103		
170				18·383	8·323	4·175	1·324	0·514	0·231	0·116		
180				20·610	9·331	4·681	1·485	0·577	0·260	0·130		
190				22·963	10·396	5·215	1·654	0·643	0·290	0·145		
200				25·444	11·519	5·779	1·833	0·712	0·321	0·160	0·087	
210				28·052	12·700	6·371	2·021	0·785	0·354	0·177	0·096	
220				30·787	13·938	6·992	2·218	0·862	0·388	0·194	0·106	
230				33·649	15·234	7·642	2·424	0·942	0·424	0·212	0·115	
240				36·639	16·588	8·321	2·639	1·025	0·462	0·231	0·126	
250				39·756	17·999	9·029	2·864	1·113	0·501	0·251	0·136	0·079
260				43·000	19·468	9·766	3·097	1·203	0·542	0·271	0·148	0·086
270				46·371	20·994	10·532	3·340	1·298	0·585	0·292	0·159	0·092
280				49·870	22·578	11·326	3·592	1·396	0·629	0·314	0·171	0·099
290				53·495	24·219	12·150	3·853	1·497	0·675	0·337	0·184	0·106
300				57·248	25·918	13·002	4·124	1·602	0·722	0·361	0·196	0·114
320					29·489	14·794	4·692	1·823	0·822	0·411	0·224	0·130
340					33·291	16·701	5·297	2·058	0·927	0·464	0·252	0·146

Table showing in feet the Head of Water consumed by Friction in each 100′ length of Pipe.

Delivery. Gallons per Minute.	Internal Diameter of Pipes in Inches.									
	3½	4	5	6	7	8	9	10	12	15
360	37·322	18·723	5·938	2·307	1·040	0·520	0·283	0·164		
380	41·585	20·861	6·616	2·571	1·159	0·579	0·315	0·183		
400	46·077	23·115	7·331	2·848	1·284	0·642	0·349	0·203	0·078	
420	50·800	25·484	8·082	3·140	1·415	0·707	0·385	0·223	0·086	
440	55·753	27·969	8·871	3·447	1·553	0·776	0·423	0·245	0·095	
460		30·570	9·695	3·767	1·698	0·849	0·462	0·268	0·104	
480		33·286	10·557	4·102	1·848	0·924	0·503	0·292	0·112	
500		36·117	11·455	4·451	2·006	1·003	0·546	0·316	0·122	
520		39·064	12·389	4·814	2·169	1·084	0·590	0·342	0·132	
540		42·127	13·361	5·191	2·339	1·170	0·637	0·369	0·143	
560		45·305	14·369	5·583	2·516	1·258	0·685	0·397	0·154	
580		48·599	15·413	5·989	2·699	1·349	0·734	0·426	0·165	
600		52·009	16·495	6·409	2·888	1·444	0·786	0·456	0·176	0·055
620			17·613	6·843	3·084	1·542	0·839	0·487	0·188	0·059
640			18·767	7·292	3·286	1·643	0·894	0·518	0·201	0·062
660			19·959	7·755	3·495	1·747	0·951	0·551	0·213	0·066
680			21·187	8·232	3·710	1·855	1·010	0·585	0·227	0·070
700			22·451	8·723	3·931	1·965	1·070	0·620	0·240	0·075
720			23·753	9·229	4·160	2·079	1·132	0·656	0·254	0·079
740			25·091	9·749	4·393	2·196	1·196	0·693	0·268	0·083
760			26·465	10·283	4·634	2·317	1·261	0·731	0·283	0·088
780			27·876	10·831	4·881	2·440	1·328	0·770	0·298	0·093
800			29·324	11·394	5·135	2·567	1·397	0·810	0·314	0·098
820			30·809	11·970	5·395	2·697	1·468	0·851	0·329	1·103
840			32·333	12·561	5·661	2·830	1·541	0·893	0·346	0·108
860			33·888	13·167	5·934	2·967	1·615	0·936	0·362	0·113
880			35·482	13·786	6·213	3·106	1·691	0·980	0·379	0·118

Table showing in feet the Head of Water consumed by Friction in each 100′ length of Pipe.

Delivery. Gallons per Minute.	Internal Diameter of Pipes in Inches.							
	5	6	7	8	9	10	12	15
900	37·113	14·420	6·499	3·249	1·768	1·025	0·397	0·123
920	38·781	15·068	6·790	3·395	1·848	1·071	0·415	0·129
940	40·486	15·730	7·089	3·544	1·929	1·119	0·433	0·134
960	42·227	16·407	7·394	3·696	2·012	1·167	0·452	0·140
980	44·005	17·097	7·705	3·852	2·097	1·216	0·471	0·146
1,000	45·819	17·803	8·023	4·011	2·183	1·266	0·490	0·152

Remarks.

This table has been worked out from the formula—

$$H = \frac{G^2 \times m \times l}{5{\cdot}5767 \times d^5}$$

Where—

H = loss of head in feet.
G = discharge in gallons per minute.
m = a varying co-efficient (*see* values below).
l = length of pipe in feet.
d = internal diameter in inches.

This formula is obtained by substitution from the formula on p. 252, J. T. Fanning's *Treatise on Hydraulic and Water Supply Engineering*, 1886 edition.

The values taken for m are—

Size of Pipes.	Value of m.	
½"	·016	Pipes of less than 3" diameter are calculated as "*foul.*"
¾"	·0155	
1"	·015	
1¼"	·01475	
1½"	·0145	
2"	·014	
2½"	·0135	
3"	·00862	Pipes of 3" diameter and upwards are calculated as "*slightly tuberculated.*"
3½"	·008435	
4"	·00825	
5"	·007985	
6"	·00772	
7"	·00752	
8"	·00733	
9"	·00719	
10"	·00706	
12"	·00680	
15"	·00646	

The velocity of flow may be obtained by the approximate formula—

$$V=\frac{G}{2d^2}$$

Where V = velocity in feet per second.

The brake horse-power of pumps may be obtained from the formula—

$$B.H.P.=\frac{G\times 10\times(H+H_1)}{33000}$$

Where
H = static head.
H_1 = fractional head.
10lbs. = weight of 1 gallon.

A residual head of 5′ at the end of distribution pipes should usually be allowed for, and minor losses of head due to bends, etc., may as a rule be neglected.

Pipes must be laid below the hydraulic mean gradient to obtain full delivery.

The values taken for *m* are—

Size of Pipe.	Value of *m*.
½"	·0255
¾"	·0243
1"	·0212
1¼"	·0145
1½"	·014
2"	·0125
2½"	·00805
3"	·008435
3½"	·00845
4"	·008265
5"	·00775
6"	·00753
7"	·00733
8"	·00713
9"	·00705
10"	·00695
12"	·00640
15"	·00610

Pipes of less than 3" diameter are calculated as "*f*ond."

Pipes of 3" diameter and upwards are calculated as "slightly rough."

The velocity of flow may be obtained by the approximate formula—

$$V = \frac{C}{\sqrt{mD}}$$

Where V = velocity in feet per second.

The brake horse-power of pumps may be obtained from the formula—

$$\text{B.H.P.} = \frac{G \times 10 \times (H + H_1)}{\text{lbs. weight of gallon}}$$

Where

H = static head.

H_1 = additional head.

A residual head of 5' at the end of distribution pipes should usually be allowed for, and minor losses of head due to bends, etc., may as a rule be neglected.

Pipes must be laid below the hydraulic mean gradient to obtain full delivery.

SECTION VII.

CAMPS AND HUTS.

BIVOUACS.

When there is no wind, spreading trees keep off cold and dew. When there is wind, look out for spots where the grass does not wave when it blows. Sleep between large fires, or if only one, sleep with feet to the fire. Remember charcoal fires in tents or huts are most dangerous. It is unwholesome to wrap up tightly in a waterproof. *It is always wise to spend plenty of time in making a bivouac comfortable.* In preparing a bed use ferns, branches, dry leaves, etc. ; on bare ground scrape a hollow for the hip at least, if not for the whole body.

Shelters may be made with sloping hurdles propped with sticks and covered with sods, waterproof sheets, blankets, etc. Two blankets laid over a horizontal string tied to two uprights can be used as a shelter for four men. Gipsy shelters can be made with flexible rods stuck in the ground round the bed, arched over it and tied together, the whole covered with any available material.

Troops bivouacking can be sheltered from the wind by a circular trench with earth thrown in to form a wall, which may be topped with branches, etc., or covered in by any temporary expedient.

If straw is available it should be made into mats ; these are comfortable and clean, they can be taken up and stacked during the day, and the ground beneath swept

clean. Loose straw is very untidy. *Fig.* 1 shows two methods of making straw mats.

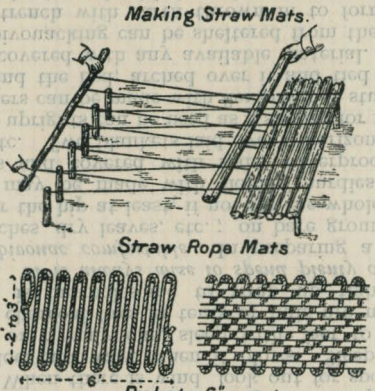


FIG. 1.

FIELD KITCHENS AND OVENS.

For a small party, hang the kettle from a tripod, or form a small fireplace of stones and clay. For a large party, dig a trench wide enough for kettles to rest easily on the edges; a chimney built of sods at the other end increases the draught. The spaces between the kettles are covered in with clay. Three such trenches (radiating at an angle of 45° with each other) form a *broad arrow* kitchen; the *gridiron* kitchen consists of nine trenches 12′ long, connected by splay mouths 18″ deep to a transverse trench 36′ long, 2′ wide and 21″ deep. The trenches are connected with the chimney by flues 9″ wide and 6″ deep, covered with the sods removed from the trenches; this kitchen can be made by 1 N.C.O. and

12 men in 8 hours. A more convenient form is the "rectangular kitchen," formed by any number of parallel trenches, each with its own chimney 9″ square. The trench should be 6″ deep under the chimney, and 18″ deep at the far end. The width of each trench is 9″, and if 12′ long will accommodate nine "large" or 11 "small" kettles, and cook for 120 men.

FIG. 2.

Fig. 2 shows a covered kitchen suitable for standing camps.

The service kettles are :—*Oval* (*large*), $7\frac{3}{4}$lbs., holds three gallons, measures $13\frac{1}{2}″ \times 9″$ and cooks for 8 men with vegetables, 15 without. *Oval* (*small*), $4\frac{3}{4}$lbs., holds $1\frac{3}{4}$ gallons, measures $12\frac{1}{2}″ \times 8\frac{1}{2}″$, and cooks for 5 men with vegetables, 8 without.

Field ovens

are of two kinds, those in which the fire first burns, makes the oven hot, and is then raked out, and those in which the fire burns below the oven during the process of baking.

Of the first, the simplest form is to take some semi-circular pieces of hoop or bar-iron, place them parallel to one another with their ends sticking in the ground ; lay sheet iron or hurdlework, or slabs of wood, over the ribs thus formed ; cover over with clay and sods, build a chimney at the side, and have a door of sheet iron in front. The tyre of a cart wheel makes two excellent ribs ; they can be put as near together as the covering slabs or sheet iron will admit, or the size of the oven dishes demands.

The objection to using sheet iron without supporting ribs is that it buckles very much when the oven is heated ; but if no ribs are available, use 12 B.W.G. sheet iron, or an arch made of hurdlework, plastered with 4″ of well-puddled clay and about 12″ of earth.

The second form of oven is shown in *Fig.* 3. The

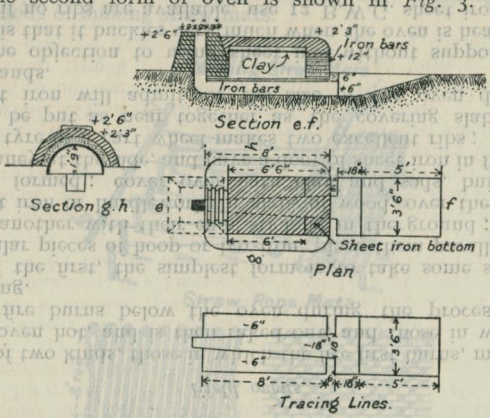


FIG. 3.

hearth should be of sheet iron. The fire should be lighted inside the oven first to heat it thoroughly, then raked out and pushed into the flue below. Supporting ribs for both arch and hearth are generally necessary.

LATRINES

should be dug as soon as the troops arrive on camping ground, and filled in before they march off. For temporary use, the usual latrines are trenches with or without seats; these trenches may be either long and deep, or short and shallow. The latter are always preferable, but the former may be required when space is restricted. If the long deep trench system is used, the trench should be about 16″ wide, 3′ deep, and with a length of 15′ for every 100 men. If the short shallow trench system is used, the trenches are 3′ long, 1′ wide, and 1′ deep, spaced 2′ 6″ to 3′ apart, according to whether the soil is firm or loose. The usual allowance of trenches of this nature is five

trenches for 100 men, but for numbers of 500 or upwards this may be reduced to three per 100 men. Fresh dry earth should be thrown in daily. A rough screen should be made round it. The site should be carefully selected, so that no filtration can reach the water supply. The cross-bar for a latrine seat should be about 2′ above ground.

TENTS.

In pitching bell tents, the points to be especially attended to are the position of the guy pegs and the precise spot the tent-pole stands on. The guy pegs must be on the circumference of a circle, of which the pole is the centre (radius 9′ 3″), and should be equidistant all the way round. The spot where the pole stands should be on the same plane as the ground on which the walls of the tent will rest. The pole itself need not necessarily be vertical, but must be perpendicular to the ground where the tent is pitched.

Of the 20 guy ropes, four have red pieces of wood marking every fifth guy, the remaining pieces are not painted.

A bell tent with its guys covers a piece of ground 18′ 6″ in diameter, so, allowing a pathway of 30″ between tents, 7 yards is the distance between the centres of two adjacent tents.

The centre of the tent should be marked by a peg, and, if possible, circles with radii 7′ and 9′ 3″ roughly traced to mark the position of walls and pegs. The tent in its bag should be laid on the ground on the side opposite to where the door will be; it should then be unpacked and laid flat out, door uppermost, and apex away from the direction of door. The guys with red pieces of wood should be drawn out, fastened to pegs driven in on the circumference, two at 45° on either side of the door, the remaining two directly opposite these. The pole may then be inserted and, supported by the four guys, the tent may be raised. The remaining 16 pegs may now be driven at equal distances on the circumference and their guys attached.

Drains should now be cut round the bottom of the tent walls.

The two mallets, peg bag and spare pegs, tent cord and tent bag, all of which are part of the equipment of each tent, should be stowed away in a definite place.

One man will pitch a bell tent as well as six men, and almost as quickly if the above instructions are followed.

In India a different pattern of tent is used, and the general size of camps for each unit is greater than at home.

GREASE TRAPS.

Waste water from kitchens and ablution benches is greasy, and if allowed to pass directly into the soil, soon makes a felt-like scum, which not only impedes the soaking in of the water, but also attracts flies.

To prevent this, the water should be first discharged over coarse brushwood, grass bracken, or gorse, etc., which catches and holds the grease and other solids, and allows the liquids to run freely into the soak-pit.

INCINERATORS.

The best method of disposing of kitchen garbage and camp refuse is by burning. There are many forms of incinerator, but an efficient one for 200 or 300 men is in the form of a chimney 5′ high and 2′ internal diameter. It is essential to provide sufficient air inlets at the base, so as always to have one or more available, according to the direction of the wind. Those inlets not in use can be temporarily stopped up. The walls may be built of any suitable materials, well plastered inside and outside with clay. The fire is started with any dry material at the bottom of the incinerator, and the refuse is gradually fed in at the top.

HUTTING.

Walls.

Brushwood, if procurable in large quantities, can be used for the walls of huts; the walls may be vertical and worked like hurdles, the webbing being filled in with mud and chopped straw (*wattle and daub*). The daub is prepared by trampling or tempering chopped straw, etc., in clay, allowed to stand for a few days if possible, and

clay, allowed to stand for a few days if possible, and

worked by hand into the brushwood. The first coat will crack on drying, another can then be plastered on.

A strong hut can be built with two walls of brushwood work with tempered clay between them. Eight men can make 100 square feet of wattle and daub walling in three hours.

In countries where there are forests, hut walls may be made of timber logs notched into one another at the ends (see *Fig.* 4). As the logs are conical, it will be wise to

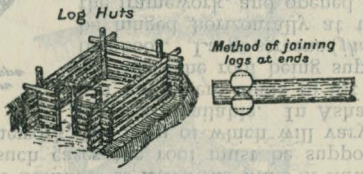


FIG. 4.

build with butts and tips alternately, thus in the first layer of four logs the two sets of butts should cross at opposite corners, and in the next layer the two sets of tips should cross at those corners. When the walls are complete, upright battens should be nailed at intervals inside, and the interstices of the logs rammed tight with ferns, moss, etc. This makes a most comfortable and substantial hut, but the labour of construction is considerable.

In stony countries *stone* may be used for the walls of huts, laid without any mortar or binding material. The courses should be regular, through bond stones should be laid in each course at 5′ intervals, breaking joint, and all the largest stones should be used for corners. Never have a longer hut than 30′ without cross walls. If mortar is procurable, lay the door and window jambs and the tops of the walls for 1 foot in it. Clay is a good temporary mortar. The thickness of the walls may be about 18″. If no stones sufficiently long to make through bonds are obtainable, pieces of flat wood laid transversely at 4′ or 5′ intervals answer the same purpose, but of

course are liable to rot. The inside of the walls should be plastered over with daub, otherwise air will enter through chinks in the stones.

In dry, hot countries, walls may be built of *mud* only. The clay is worked up with water and laid in layers about 12″ to 18″ high, and from 18″ to 2′ thick. As soon as one layer is dry and slightly cracks, another layer can be built above. This is called *puxa* or *pisé* work, and is common in certain parts of Asia and Africa. If required to last for any time the walls should be plastered with daub.

In such countries *sun-dried bricks* are very useful. They are made of clay mixed with a little chopped straw, pressed into moulds and dried in the sun. The mortar used is simply mud.

In China, huts were rapidly made as follows :—The roof timbers were first erected, supported on wooden pillars. Fascines of coarse grass or stalks of millet were then laid over the roof timbers close together and plastered with clay and chopped straw. This formed a warm and fairly dry roof. The walls were then built of millet stalks placed vertically and plastered on both sides.

It may be desirable to leave the walls of huts partially open. In such cases the roof must be supported on a timber framework, the form of which will vary with the material available. In Ashantee, canvas walls were made to lift up in the daytime, the roof being supported on bamboos. Large screens (*jhamps*) may be hinged horizontally at the top of the framework, and opened or shut at will.

FIG. 5.

Fig. 5 shows a suitable form of hut on a steep slope.

FIREPLACES.

Fireplaces are required in all huts used in cold countries. They require careful making to prevent setting the structure on fire. The inside of the flues should be well plastered with mud. Bricks, either burnt or sun-dried,

are the best materials, but sods can be used if well picketed. Iron band gabions lined inside with sods do very well. *Figs.* 6 to 9 show various forms of chimneys.

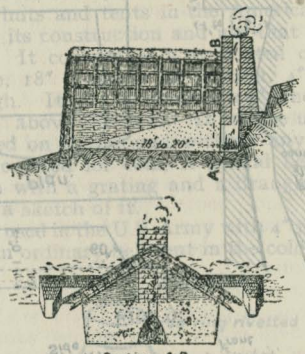


FIG. 6.

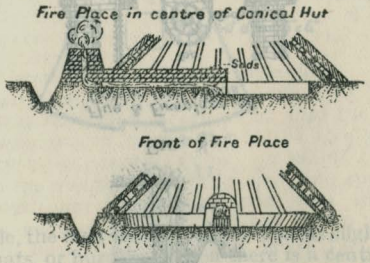


FIG. 7.

The interior cross section of the flue should be at least 80 square inches throughout. *Fig.* 10 shows a form of fireplace built of bricks which was found very useful in China during the severe winter of 1900-01. Iron bars

FIG. 8.

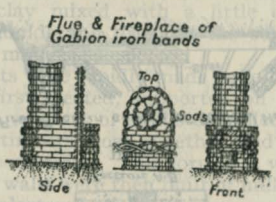


FIG. 9.

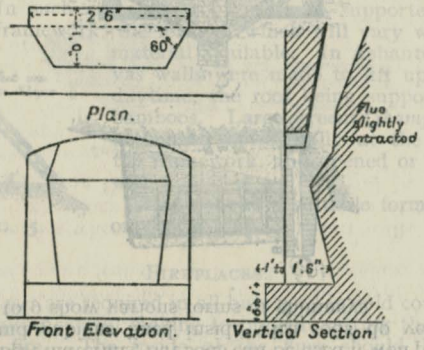


FIG. 10.

were used when coal was burnt, but were not required for wood.

A good form of stove, known as the Sibley Stove, is used to warm huts and tents in the American Army; it is so simple in its construction and use that a description is here given. It consists of a truncated cone of sheet iron, 18 gauge, 18″ diameter at bottom, 4″ diameter at top and 2′ high. It has a door 6″×6″, the lower edge of which is 10″ above the base. It can be used for wood by being placed on the ground without any special platform, but if required for coal, it should be placed on a brick platform with a grating and a draught hole below. *Fig.* 11 shows a sketch of it.

This stove is used in the U.S. Army with 4″ piping. One is sufficient for an ordinary bell tent in the coldest weather.

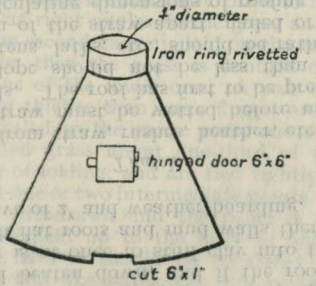


FIG. 11.

FLOORS.

If possible, the men should sleep on boards slightly raised, on straw mats, or hurdles. When there is a central passage in a hut it should have about 6″ of gravel spread over it. Cowdung mixed with clay gives a smooth good floor.

ROOFING.

The *roofing* of huts is always the chief difficulty. In dry, hot countries the roof must keep out heat, so either

the *flat roof* or thick thatch is the best. The former should be laid at a slope of not more than 1 in 20, and is made as follows :—Over the roofing joists are laid short pieces of stick close together ; these are generally from 2′ to 4′ long, roughly squared, and about 1½″ to 2″ thick (if the roofing joists are more than 2′ apart, they will have to be longer and thicker). Over them is laid sometimes matting, sometimes light brushwood, and then damp clay. Over the damp clay is drier clay, and the whole is finished with a rendering of daub. In laying the clay it should be well beaten down, and if the roof leaks, the way to stop it is at once to stuff clay into the leak and press it. With flat roofs and mud walls there should be a projecting eave of 2′ and weather boarding.

Thatch

may be made from straw, rushes, heather, etc., the longer the better. Straw must be wetted before use, and laid ears downwards. The roof has first to be prepared as for slating, the slope should not be less than ¾, and the horizontal battens, laths, etc., should be rather less than half the length of the straw apart, nailed or tied to the rafters (for calculating dimensions of roofing timbers, see Section I.). The thatching commences at the eaves ; the first layer should be at least 6″ thick at the eaves, decreasing towards the upper end. Each layer should just overlap that next but one below it. The layers of thatch may be sewn to the rafters with stout cord or spun yarn, two men working one above and one below, the sewing being done with a coarse needle, or splint of wood with sharpened point. Another man passes the straw up to the thatchers. Three men should do 15′×7′ in 8 hours.

A better method is to lay a *thatching piece, i.e.*, a rod not more than 1½″ thick, flat if possible, on the butt end of the straw and secure it to the roof timbers below by nails or yarn.

In laying ridges, thick straw should be put across saddle-fashion and secured by *ridging pieces* on either side.

These may be nailed to the roof below or fastened down by *splinters*, *i.e.*, rods about 18″ long, sharpened at both ends, and then twisted in the centre, so that the two ends can be brought parallel to each other, but not without the exertion of some force.

The outside of the thatch should be combed down when finished, and should have an even surface.

A third way is by making the straw into panels, which can be made up while the walls and roof are in progress, and can be very quickly laid like slates when the roof is ready. The tools required are one billhook and two gauge rods (about 6′ long and 1″ in diameter). The size of the panels is limited by the available length of the rods; 6′ is generally convenient, but they need not be all the same length. One rod is laid on the ground, the grass or straw is spread evenly along it sufficiently thick to hide it. The rod should be at right angles to the grass and just under its centre. The second gauge is laid on the top, just clear of the first one, then the grass is doubled over the top gauge by means of the lower one. A pair of light rods (not necessarily thicker than one's finger) are then taken and placed parallel to the gauge rods, one over and one under the folded grass about one-third of the distance from the point of folding, and are tied tightly together at the ends and at one or two intermediate points. The gauge rods are then withdrawn and the panel is ready. The panel should be held up to the light to find where the thatch is thin, and it should be regulated accordingly. The panels are laid like slates, the rods being tied to the woodwork of the roof, each successive layer overlapping to cover at least one-third of the panel below. At the ridges a new rod is tied at one end over the rods of the top panel at each side, grass is then bent over the ridge and the ends passed under the new rods, which are securely tied, at about 18″ intervals, to the rods of the panels below as the ridge grass is put under them, and so on until the ridge is completed. To prevent the wind blowing up the bottom layer, it is secured by rods along the eaves, one just above and one below the ends of the rafters, which are tied together.

Manufactured Roofing Materials.

Corrugated iron, No. 20 B.W.G. (weighing 217lbs., and costing 33s. 4d. per 100 square feet), is sometimes worth using. To fasten it, rivets should be dispensed with. Clips should be used as in *Fig.* 12. The overlap should be at least 8″ and $1\frac{1}{2}$ corrugations laterally. The advantage of this arrangement is that the sheets are not cut by rivet holes, and can be used again.

FIG. 12.

Galvanized sheet iron, No. 22 gauge, laid on the "Naini-Tal" system, as invented by Sergeant Mackenzie, R.E., is much better than corrugated iron and can be very quickly applied. The sheets are 6′×2′, and are made up in bundles fastened together with iron bands, which can be most profitably utilized in the roof work. These sheets may be laid either on planking or horizontal battens, but in either case it is necessary that vertical battens 2″×$1\frac{1}{2}$″ should be nailed at intervals of 1′ 8″ in the clear. One-fourth of the total number of iron sheets should be set aside for cutting up into covering rolls; for this purpose each sheet should be cut into four strips, each 6′ long by 6″ wide. Each strip is then hammered by a mallet in a gauge till it assumes the shape of the letter C.

The remaining sheets have the edges hammered over so that they can fit in a gauge 1′ 8″ wide. They are then laid upon the roof and fit in between the vertical battens. Short pieces of flat iron from the bands are screwed into the batten and hold down the sheet on each side, and then the covering roll is slipped over the whole. *Fig.* 13 shows a horizontal section of the roof. At the ridges a flat board may be laid, abutting on either side against the ridge-piece and resting on the vertical battens; the sheets are laid on this longitudinally, one end only being turned up, and covering rolls are laid over. In this way ridge ventilation is secured (*Fig.* 14).

FIG. 13.

The advantages of this system of roofing are :—(1). That there are no rivets or holes exposed in the outer covering which can produce leakage. (2). That although everything is fastened, no sheets are rigidly fixed, so that there is every allowance for expansion and contraction. (3). That it can be very quickly put up, more so than any other form of roofing. (4). That unskilled labour can prepare the sheets, and thus the troops can assist in hutting themselves. (5). When no longer required, the whole material can be used again.

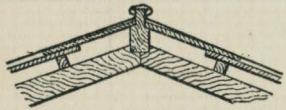


FIG. 14.

Galvanized iron is best, but plain sheet iron can be used. It should be either tarred or painted, or it will rust.

At the eaves it is advisable to put clips screwed to the rafters below, or a strong wind may strip the roof.

Sheet iron can be used for the walls of huts, fastened to a framework of studs, sills, and braces. If used both outside and inside of such a framework, and if the space between be filled with sawdust, it makes a warm hut; but planking is to be preferred for the inside if procurable.

Willesden paper supplied in rolls 19″ and 60″ wide weighs about 16¼lbs. per 100 square feet.

Roofing felts are sold of different varieties. Most of them require tarring after being laid on, which is objectionable. The best sort for military purposes is that sold by Messrs. Anderson & Son, Roach Road Works, Old Ford, London, E., which is specially prepared; not necessary to tar when first placed; is made in rolls of 200′ super, 32″ wide, 25 yards long. A package of four rolls in a crate weighs about 4cwt. 1qr.; 100′ super. weighs 50lbs., and costs 4d. per lineal yard.

SEMI-PERMANENT HUTS.

Each man should have 600 cubic feet in barracks, 1,200 in hospital; and each horse in a stable should have 1,500 cubic feet, and ridge ventilation.

FIG. 14.

The advantages of this system of roofing are :—(1). That there are no rivets or holes exposed in the outer covering which can produce leakage. (2). That although every thing is fastened, no sheets are rigidly fixed, so that there is every allowance for expansion and contraction. (3). That it can be very quickly put up, more so than any other form of roofing. (4). That unskilled labour can prepare the sheets, and thus the troops can assist in putting themselves. (5). When no longer required, the whole material can be used again.

Galvanized iron is best, but plain sheet iron can be used. It should be either tarred or painted, or it will rust. At the eaves it is advisable to put clips screwed to the rafters below, or a strong wind may strip the roof.

Sheet iron can be used for the walls of huts, fastened to a framework of studs, sills, and braces. It used both outside and inside of such a framework, and if the space between be filled with sawdust, it makes a warm hut; but planking is to be preferred for the inside if procurable.

Wilsden pegs supplied in rolls 10" and 20" wide weighs about 10 lbs. per 100 square feet.

Roofing felts are sold of different varieties. Most of them require tarring after being laid on, which is objectionable. The best sort for military purposes is that sold by Messrs. Anderson & Son, Roach Road Works, Old Ford, London, E., which is specially prepared ; not necessary to tar when first placed ; is made in rolls of 20' super. 32" wide, 25 yards long. A package of four rolls in a crate weighs about 1cwt. 1qr. ; 100' super. weighs 50 lbs., and costs 4d. per lineal yard.

SEMI-PERMANENT HUTS.

Each man should have 600 cubic feet in barracks, 1,200 in hospital ; and each horse in a stable should have 1,600 cubic feet, and ridge ventilation.

SECTION VIII.

SEMI-PERMANENT HUTTING.

Temporary accommodation for troops is often required at very short notice, as for instance, on active service, or during mobilization at home, or pending the provision of permanent barracks, or in the case of labour camps. The buildings provided in such cases vary immensely in type, cost, and construction, and there can be no fixed types. In all cases permanence is of no account, the essential factors being cheapness and rapidity of construction.

The types described in the following pages are all what may be called "wood and iron" huts. These fulfil the necessary conditions of speed in erection and economy, in most localities where huts are likely to be required, better than any other type; but it should be clearly understood that no type can be labelled the best, for in each case, besides local climatic conditions, local labour and materials, their cost and the quantity immediately available must be carefully considered. For example in the East where burnt bricks may be twice and sun-dried bricks thirty times as cheap as ordinary bricks are in England, where the labour for laying them is also much cheaper, and where corrugated steel, and wood cannot be obtained in large quantities and are moreover very expensive on account of cost of freight and transport, mud or rough masonry huts may be much the cheapest and most rapidly erected type of building, besides being more suitable to the climate. The best "hut" in a foreign country is usually an adaptation of the local type to the particular conditions that arise.

Speed and economy can be obtained by reducing the scale of accommodation and by altering the details of

construction of permanent buildings. If accommodation is to be cut down without rendering the building unnecessarily uncomfortable, the first consideration is the organization of the people to be housed.

In housing civilian labourers the grouping and design of buildings must suit the organization and habits of their tenants. Thus, though foremen correspond in some respect to N.C.O.'s, they would not be placed in small rooms in the labourers' huts, as they have no authority over their men out of working hours.

It is unnecessary to lay down anything more definite about reductions in accommodation for economy's sake than has been said. The point is to consider every item on its merits. Every item is not necessarily reduced, *e.g.*, if dining rooms are omitted, barrack rooms may have to be larger to take the dining tables. When a building only occurs once in a scheme, an institute for instance, drastic reductions should be avoided as it saves little and causes discomfort, but when a building, such as a barrack hut, is repeated many times opportunities for economy in its plan should be carefully considered. Repetition work should be adhered to as much as possible, *e.g.*, one span for all, or nearly all the buildings, standardized spacing of trusses, timber scantlings, lengths of corrugated steel sheets, etc.; neglect of this important rule will result invariably in waste of money and great waste of time.

"Wood and Iron" Huts.

There can be considerable variations in the materials used and the methods of construction; but the commonest arrangements will be described first, and variations noted at the end.

The reasons why this type of hut can be so cheaply and rapidly erected in certain situations should be noted. The materials, besides being cheap in themselves, are light and easily transported without breakage in bulk, therefore carriage is cheap also. The market sizes can in most cases be used as they can be adapted quickly with little labour to a variety of buildings. The supply of materials

in the market is usually considerable and can be rapidly supplemented on emergencies. Corrugated sheets are large and need few fastenings so that large areas can be covered with little labour; moreover being stiffened by the corrugation, wall bracing can be a minimum. Finally, all material being dry, huts can be occupied directly on completion.

Before describing designs a few notes on the two principal materials may be given.

Timber.—The timber is usually yellow deal of cheap quality, and nothing better is required. Its characteristics need no description here. In England the market forms are, *planks*, 11″ to 18″ wide by $3\frac{1}{4}$″ to $4\frac{1}{2}$″ thick; *deals*, 9″ wide by $2\frac{1}{4}$″ to 4″ thick; *battens*, 5″ to 7″ wide by $1\frac{3}{4}$″ to $2\frac{3}{4}$″ thick approx.; *flooring* (with prepared edges), $\frac{3}{4}$″, 1″, $1\frac{1}{4}$″, and $1\frac{1}{2}$″ thick by $4\frac{1}{2}$″, $5\frac{1}{2}$″, and 6″ wide and *matchboarding* for linings, etc., down to $\frac{1}{2}$″ thick. Sometimes a local market, especially abroad, restricts itself to certain scantlings, and in such cases the *local market sizes* should be ascertained before designing. On the other hand, if local market sizes are not convenient, other scantlings may be cheaply obtainable if a large order is given. (This applies to all materials that are not strictly local). In all cases as few different scantlings as possible should be used. It prevents confusion, and material, as it arrives, can be used at once on any building that is in hand. Larger scantlings should be built up by 2, 3, or 4-ply work as may be necessary.

Corrugated Steel Sheets.—Corrugated steel sheets for ordinary W.D. work are obtained under a D.F.W. Contract. Whether obtained this way or not the contract schedule is always a useful guide, giving the sizes and gauges in common use. Table I. is based on it. In rapid work galvanized steel sheets are fastened to woodwork by passing galvanized steel screws through punched holes, the screws being hammered in over a washer. The screws, washers, etc., are supplied by the same manufacturers. It should be remembered that the longer the sheet the less the waste in lap, and the less the labour required to fix.

Area covered by One Ton of Corrugated Sheets after allowing for the Laps.

Gauge ..	16	18	20	22	24	26	28
Square feet ..	600	800	1,000	1,200	1,500	2,000	2,200

Approximate Weight of Corrugated Sheet Roofing or Sides of Building, per 100 *Super. Feet.*

Gauge	18	20	22	24	26
Weight in lbs. ..	273	217	175	147	112

TABLE I.

Corrugated Steel Sheets.

Gauge.	Length.	Weight of 10 Corrugated Steel Sheets in the Black.		Weight of 10 Corrugated Steel Sheets Galvanized.	
		cwts.	lbs.	cwts.	lbs.
	ft.				
No. 22 B.G. (1884), 2′ 2″ wide, with eight 3″ corrugations ¾″ deep, stamped from 2′ 5½″ sheet in the flat.	3	—	93½	—	102½
	4	1	12	1	25
	5	1	43½	1	59
	6	1	75	1	93
	7	1	106	2	16
	8	2	24	2	49
	9	2	56	2	83
	10	2	87	3	0
No. 20 B.G. (1884), 2′ 2″ wide, with eight 3″ corrugations ¾″ deep, stamped from 2′ 5½″ sheet in the flat.	3	1	5½	1	14½
	4	1	44½	1	56½
	5	1	84	1	98½
	6	2	11	2	28½
	7	2	50	2	70½
	8	2	89	3	1
	9	3	16	3	42
	10	3	55	3	84
No. 18 B.G. (1884), 2′ 2″ wide, with eight 3″ corrugations ¾″ deep, stamped from 2′ 5½″ sheet in the flat.	3	1	36	1	44
	4	1	85	1	96
	5	2	22½	2	36
	6	2	72	2	88
	7	3	9	3	28
	8	3	58	3	80
	9	3	107	4	19
	10	4	45	4	72

Walls and Foundations.—Such a hut is very light, therefore the distribution of its weight on the ground rarely needs consideration. All that is necessary is a level floor or sills to stand the framing on.

A hut may be supported on a few rows of sleeper plates, parallel to its length, say four rows to a hut 20′ wide (*vide Figs.* 3, 6, 9, and 10). The outer two are under the side wall frames. The inner sleepers give intermediate support to the floor joists. The sleepers may rest either on a concrete slab 6″ thick (which acts also as a ground seal), or else on rows of stumps. The stumps should be about 4′ apart, exact spacing being unimportant, bedded in the ground and cut off level at the height of plinth required. If huts are raised on stumps the latter should be high enough to give access underneath the hut for cleaning, and *if possible* a rough concrete seal should be given as well.

It is of course very necessary to fix the hut securely to the foundation or stumps to prevent its being blown over by high winds.

If the framing has uprights at short intervals and roof trusses are light (as is usually the case), the wall frame can be considered as a solid wall and the position of uprights with reference to the trusses above and the piles beneath is immaterial.

Where however the roof trusses are of such a span and spacing as to be of considerable weight it is best to provide uprights in the framing directly underneath them. These uprights are let into the ground about 3′ and rest on wooden shoeplates to prevent them sinking (*vide Figs.* 12 and 13). The wall framing is then built into these uprights and the floor is supported on sills as before.

Wall Frames.—The drawings (*vide Figs.* 5, 6, and 7) explain the framing clearly. Each steel sheet of the length shown should be fastened to at least three horizontal timbers. It is usual to give four rows of fastening for 10′ sheets, the two intermediate supports being arranged to fit in with door and window openings, etc. Diagonal bracing is often unnecessary in huts of *ordinary* size as the corrugations of the sheets stiffen the structure. In considering the strength of a hut it should be looked at as a whole.

Individual frames of the dimensions illustrated doubtless look light. When connected however the frames support each other and the roof ties the whole together. A hut is really a light box.

The following are important points :—The cutting of sheets should be avoided as much as possible, and the height of wall frames and as far as possible openings in the framework should be arranged with this in view. Framing, including bracing, should come up to a level face inside and out, so that the covering may be fixed without packing pieces. Mortise and tenon joints need only be used sparingly for main joints. Elsewhere use spikes and hoop-iron straps. The corners of huts need slightly heavier scantlings and secure fastenings. Partitions are lighter stuff but are framed in the same way as outer walls.

In erection the quickest way is to put whole frames together on the ground and hoist them up bodily on completion.

A hut is ill-adapted to resist wind pressure, during construction, until the frames and covering give mutual support and the base is securely fixed to the foundations.

Hoop-iron or bolts should be used freely to fasten sleeper plates to every alternate stump, trusses to top plates, purlins to alternate rafters, and verandah posts at both ends.

Roofs.—Spans should be kept small. Large spans involve heavy trusses and special arrangements for supporting them. Except for special sheds 24′ should be the maximum : and as far as possible the same span should be used throughout. King post trusses are unnecessary. Collar beams (*Figs*. 6 and 10) should be used for preference as extra headroom can be managed, without the use of tie bars, which are liable to damage from unauthorized loading. A total working load of 20lbs. per sq. ft. is all that need be allowed.

Ridge ventilation requires careful work, for heavy rain and dust are difficult to keep out if the ventilators are not carefully designed. In cold climates they are required only in special cases such as cookhouses where there is a considerable amount of steam (*Fig*. 8).

Metal roofs are thin and very conductive of heat, so that ceilings should be given, and the walls should be felted and match-lined.

Where funds and time permit, provide eaves boards, barge boards and finials. When cantonments are occupied for some time any "finish" of this kind, which makes the building look less box-like and depressing, is an advantage, but the boards should be solidly made and all elaborate ornament should be avoided (*Fig.* 8).

Galvanized ridging is obtainable in 6′ lengths. This can be used inverted for valleys, but valleys should be avoided as much as possible. Guttering is quite unnecessary except over entrances. Flashings should be zinc or plain galvanized steel sheets.

Where flue-pipes from stoves pass through walls or roofs, the iron pipe should pass through a stoneware drain-pipe, and be packed with cement (*vide Fig.* 8).

Floors.—For floors the sleepers should be sufficiently close to make the joist spans about 6′. Use light joists at 12″ to 18″ intervals. Boarding should be $4\frac{1}{2}'' \times 1''$, *grooved and tongued.* If possible put a harder pine floor in hospitals. Skirtings can be quadrant or $9'' \times 1''$ boards. The same scantlings can be used for skirtings, eaves boards, etc., with advantage. Good workmanship, with the use of proper cramps and a sufficiency of nails, should be insisted on in flooring; otherwise the hut will be extremely draughty. Open boarding in verandahs is not recommended, for small articles fall through and dirty water fouls the ground below. Kitchens, ablution rooms, etc., must have concrete floors, so that these floors must not be much above ground level. Details are given on *Fig.* 9.

Doors and Windows would be obtained wholesale ready-made or put together at a base in large quantities, so that labour-saving machinery may be economically used. In most cases frames need not be supplied with them as they add to the cost of carriage. They can be made up of light stuff on the site and worked in to fit the main framing of the hut (*Fig.* 9).

Casement windows with hopper lights at the top are the

most convenient. Casement stays are essential to prevent extensive breakages in high winds.

Ceilings and Linings are essential owing to the conductivity of the metal covering. They are usually $4\frac{1}{2}'' \times \frac{5}{8}''$ ($6'' \times \frac{1}{2}''$ is possible but not recommended) matchboarding (grooved and tongued), but they can well be thicker in the more important buildings. Walls should have sarking felt under the lining or, if nothing better is available, tarred paper. Alternative materials for linings are asbestos sheets, plaster on expanded metal, "Compoboard," "Beaverboard," and Willesden canvas. Ablution rooms, etc., must have steel sheet or other waterproof lining 5′ 6″ high.

The general principles of planning that apply to permanent buildings apply also to huts, but the necessity for speed and economy and the consequent type of construction described above involve attention to the following points :—

Planning.—To facilitate erection the aim should be to make the constructional details of all huts as similar as possible. In planning therefore we should avoid anything that leads to variations in details of wall framing, trusses, etc., or anything needing particular skill or supervision. Each hut, in plan, should be if possible a single rectangle without excrescences. Where annexes are necessary, horizontal roof valleys are to be avoided as they are difficult to make watertight when construction is light and hurried. Trusses of only one or possibly two different spans should be used throughout the scheme. Annexes should be roofed with some of these standard trusses (*vide Figs.* 1, 2 and 3).

Timber scantlings should be of 1″, $1\frac{1}{2}''$, or 2″ stuff, built up in 2, 3, or 4-ply work.

If economy in water supply or drainage will result from any device such as putting the sanitary annexes of one row of huts at their east ends, but the annexes of the next row of similar huts at their west ends, such a change in planning should be considered. It may involve little real alteration in constructional details, being merely inversion. Again, if some rooms in a building must have

concrete floors it will usually be economical to group them all together.

In temperate climates verandahs are rarely necessary for giving shade, but they may form useful additions to rooms which are otherwise somewhat cramped in warm weather. They are also a cheap form of passage, and outside offices, etc., come in useful for waiting orderlies. A verandah should only be put in for a definite object and should then be dimensioned accordingly. Thus if it is primarily meant as additional sitting or sleeping space it is useless unless at least 6′ wide, whatever its length, while a passage verandah need never be more than 5′ wide.

Native Prejudices: Labour Camps.—All the foregoing remarks apply particularly to the hutting of white people, civil or military. Where natives are concerned, people who are not accustomed to dealing with them require to be reminded of several points. The natives may be either troops or labourers. It is hopeless to keep a cantonment, built or building, in a sanitary condition if the natives employed therein come daily from insanitary surroundings. Where natives are concerned their organization and habits must be considered; ignoring them will result in driving native labour away, and in creating disturbances and discontent. A native camp may contain several groups differing widely in religion and social habits, and they need separate cookhouses, washing places, and so on, designed to suit them.

A labour camp grows only gradually in numbers as work develops, and its small size at the start tends to obscure the necessity for planning and regulation, the result being an irregular, dirty, and uncontrollable native village when the numbers increase. If there is reason to expect a large camp the sites for all future shops, watering places, etc., should be decided on at the start, and some subordinate should be made definitely responsible for order and sanitation.

In the case of a military cantonment, the growth is not so great, but the planning of it, in any case, must be with an eye to future developments, and the special require-

ments of native troops, both from a social and religious point of view, strictly attended to.

Alternative Methods of Construction.

As the materials used would be decided by local conditions it is impracticable to describe all the combinations that might be used ; but a few of the principal alternatives to " wood and iron " are noted below so that they may not be lost sight of.

Masonry Walls for huts may be quite cheap and rapidly erected where labour is cheap and the stone obtainable near the site. If permanence and appearance are no object, the labour on the stone itself and in setting it can be reduced to very little, and then the principal cost of masonry work disappears. The low walls of huts can easily be built of very roughly dressed stone, and sometimes of undressed water-worn stones. The interior mortar can be mud, protected by lime mortar pointing. Walls can be built of dry stones, also with wooden ties used at intervals. Where it is not economical or convenient to build the main walls of huts in masonry it may be best to support the framework on masonry dwarf walls or pillars.

Brick Panelling can be combined with wooden framing. If protected from the weather by plaster or weather-boarding it can be sun-dried bricks only.

Plaster on Expanded Metal makes a good covering, inside and out, for timber-framed huts. The metal comes in large rolls which can be reeled off straight on to the sides of the hut and rapidly fixed.

Sun-dried Bricks are quite practicable for hut walls, even in wet climates, if the brick clay is good, well puddled, and protected from the weather by plaster. The plaster may require frequent repairs, but the cost is negligible where labour is cheap.

Mud Roofs, 6″ thick, and properly plastered, are very cool and will stand the heaviest rain, but not snow ; a protective weather covering of corrugated steel sheets is sometimes used.

Patent Felt Roofs.—There are several varieties, Ruberoid, Rok, Congo, etc., but they are very much alike. Each is sold in two or three thicknesses (*e.g.*, Ruberoid, 44lbs., 60, 82, and 100lbs. a roll) and of two or three different colours. The material is made up in convenient rolls, each containing sufficient to cover 200 square feet, the necessary nails and cement being included. All these materials must be laid on close boarding.

Asbestos Slates and Sheets.—The commonest trade varieties are Poilite, Uralite, and Eternit, all being much alike. Sheets are obtainable up to 8′×4′. The material is a good non-conductor and easily worked, but it is liable to considerable breakage in transit, and warps if freshly made, so seasoned stuff at least six months old should be insisted on. Sheets should be $\frac{3}{16}$″ and slates $\frac{5}{32}$″ thick as a minimum. Sheets should have trimmed and rectangular edges. Slates should be delivered holed for $3\frac{1}{2}$″ lap. 1,000 asbestos cement slates ($15\frac{3}{4}$″×$15\frac{3}{4}$″) cover 10 squares, and weigh 250lbs. per square.

Shingles.—These are really wooden tiles, and should be about the same size as clay tiles. In the best work they are split, but sawn ones will serve.

Roofing Felt, tarred and laid on boarding, is sold in rolls 25 yards by 32 inches, which should weigh about 100lbs. a roll. It must be fastened with special felting nails.

HUT HOSPITALS.

The methods of construction already described apply also to hospital huts; but the distribution and planning of hospital hutments require special notice.

For instance, in the case of a large base hospital, wholly or partly accommodated in huts, the questions of its arrangement and of the scales of accommodation present some difficulties. The new hospital synopsis has not yet been published, and as existing military hospital buildings have been designed to meet the particular requirements of each station or district, the knowledge of what is essential in temporary buildings is not so common or so easy of acquirement as in the case of barracks. Therefore some

notes are given as to what a hospital of this kind might require, but they can only be generally applicable because in temporary, as in the case of permanent work, requirements, funds, and time available vary greatly in each case. They will prevent, however, any essential item being forgotten.

In the first place it may be remarked that, when it is a question to what extent huts should be provided at all for a given hospital, it must be remembered that the danger to the sick in tents is not principally due to their actual personal exposure to the weather. The danger arises from possible contamination to ill-protected food, from septic conditions during operations in places exposed to dirt, and from the inevitable shortcomings of camp sanitation.

The first consideration should therefore be to make use of huts to improve sanitation; therefore cook-houses, latrines, ablution rooms, and operating rooms are the first requirements. Hut wards for special cases and huts for administrative buildings and stores which will facilitate the working of the hospital come next. Ordinary wards, the quarters for the *personnel*, etc., should come last of all.

As an example we will take a General Hospital (520 beds), which very probably might be accommodated entirely in huts. The "war establishment" for this hospital is 21 officers, 2 warrant officers, 13 sergeants, 2 buglers, 8 corporals, 118 privates, and about 43 nursing sisters. If no female nursing staff were available 36 N.C.O.'s and men would take their place.

The buildings required are given in the following list, with a brief description of each. The order of their importance and in which they would be built has already been indicated.

Ward Hut.—A nurse cannot supervise properly more than 32 beds. If the wards contain less than 20 beds each there is a waste of staff and waste in first cost, for ward accessories (lavatories, etc.) have to be repeated for every main ward, however small. To avoid inordinately long huts about 24 beds per ward is best. A typical ward hut

is shown on *Figs.* 10 and 11. The minimum area and cubic space given in permanent hospitals should be adhered to if possible (viz., 84 f.s. and 1,200 c.f. per bed). If a reduction is necessary it should be rather in the height of the building than in its floor area.

Every hut ward should have a nursing duty room, a small ward (one or two beds) for special cases, and a scullery and larder; also a linen store, unless centralized linen stores are considered more convenient, in which case cupboards would be given in each ward. Entirely apart from these rooms and with thorough cross ventilation between it and the ward there must be the usual sanitary annexe containing closets, bathroom, and sinks.

Verandahs, if any, should be 8′ wide at least, *i.e.*, the length of a bed plus passage space. Some of the ward doors must be 4′ 6″ wide to pass beds, and all main doors should permit of a man on a stretcher being carried in and out. Each bed should be next a window. The floor should be as good as possible, and washable walls (or at least a high dado) should be provided. The exclusion of mosquitoes, flies, dust, and glare are points to be considered, and self-closing doors to cook-houses, etc.

Clean Linen Store (about 40′ × 20′) and a *Foul Linen Store* (14′ × 20′) will also be required. They are extra to the usual ward stores. The former should have 2′ shelves and a serving counter near the door. The latter should have an impermeable floor and no shelving.

Steward's Store (about 30′ × 20′), *Utensil Store* (20′ × 20′), and *Quartermaster's Office* (10′ × 20′) are in one hut. The steward's store should be in two compartments (store and issuing), and should have a concrete floor and plenty of 18″ shelving. The utensil store should have a concrete floor and 2′ shelving.

Pack Store (56′ × 20′) and *Rifle Store* (10′ × 20′) in one hut. The former should have 2′ shelving for about 500 kits, the latter rifle racks. Both stores should have concrete floors and ample light and ventilation.

Dispensary (28′ × 20′) and *Pathological Laboratory* (20′ × 20′) in one hut. The former requires a separate issuing compartment, counter, sinks, and ample shelving. The

details of the latter must depend on local conditions—like an operating room it must be as aseptic as possible.

Operating Room.—A type design for this and the necessary accessory rooms is given on *Figs.* 16 and 17. The structural details to note are good north light, no roof lights, impermeable floor (concrete or linoleum-covered wood), good ventilation, access for wheeled stretcher, washable walls, and elimination of everything liable to collect dust or dirt. Two lamps of 100 c.p. each above the table and two hand lamps are necessary.

Disinfecting Sheds.—A considerable amount of apparatus would be installed if the hospital were in use for any length of time. Details would vary in each case, but one hut containing the following divisions would have to be allowed for in an estimate. A type plan is given on *Fig.* 18 for general guidance only.

Clothes Disinfecting Shed (about 15′ × 15′), where clothes are steeped in disinfecting solutions.

Clothes Boiling Shed, where very foul clothes are boiled.

Steam Disinfector Shed (25′ × 15′).—This would be divided into two compartments, one for infected, the other for disinfected clothing, the steam disinfector being fixed in the partition wall.

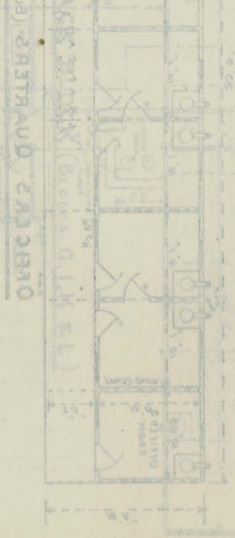
Quarters.—The hospital establishment would be divided into three camps, Medical Officers', Nursing Sisters', and R.A.M.C. rank and file. The first two would need similar accommodation such as mess, etc. The third would require ordinary hut-barrack accommodation, as described earlier in this section.

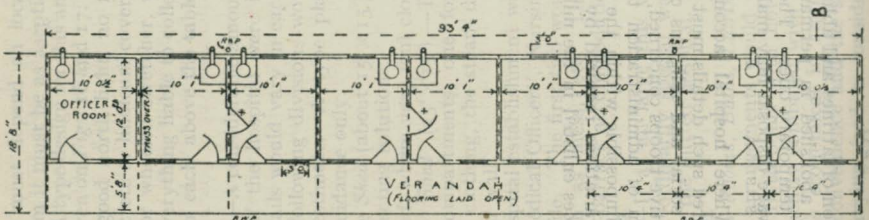
Officers' Hospital.—If at all large this would require a separate mess; but ordinarily special wards for officers would be included in the hutted hospital. For an outline type plan see *Fig.* 19.

Kitchens, Ablution Rooms, Baths, Latrines.—No details can be given. The arrangements would vary greatly in different localities. Bathrooms with hot water laid on can be often conveniently combined with kitchens. Centralized kitchens are economical in staff and fuel, but they increase the inconvenience and the sanitary dangers that arise from carrying food a considerable distance.

Excessive centralization of latrines and ablution rooms, an evil which has been abolished in permanent barracks, should be avoided in temporary ones. The difficulties of water supply and sewage disposal may make it necessary to a certain extent.

Native Troops.—Where hospital accommodation for native troops is required such details must be designed in accordance with the social and religious customs of the different classes of native troops concerned, and in accordance with the system of administration that applies to them. It would be impossible within the scope of these notes to detail the variations required by the multitude of different native races enlisted in the military forces of the Crown.

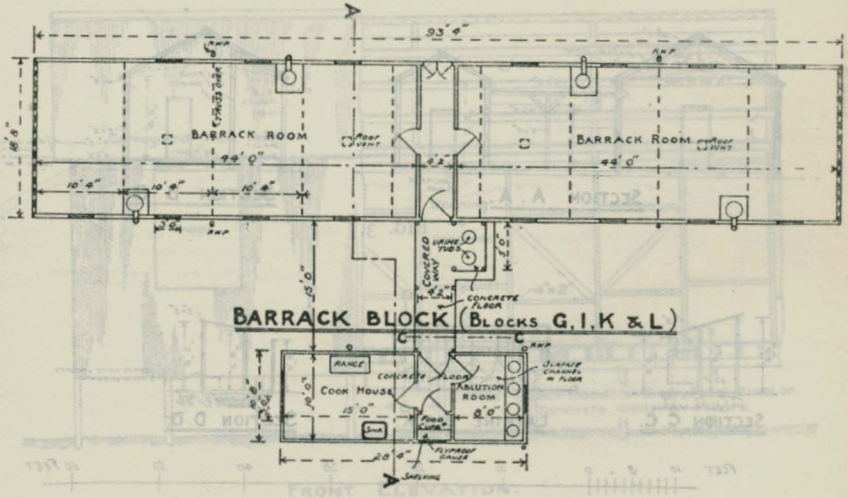




OFFICERS' QUARTERS (BLOCKS A.B.C.E F & H.)

Note.—Doors marked * to be provided in Block "F" only.

FIG. 1.



Note.—The cook house to be store for blocks "K" and "L."

FIG 2.

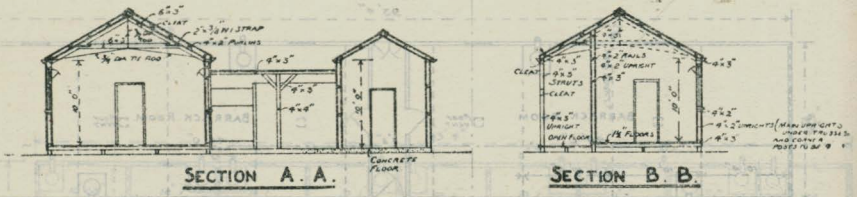

SECTION A. A.
CONCRETE FLOOR
SECTION B. B.

FIG. 3.

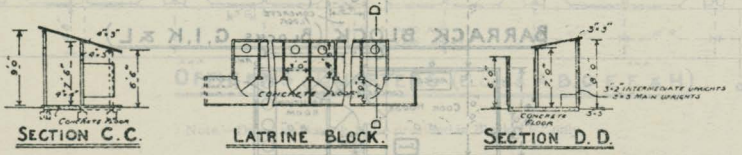
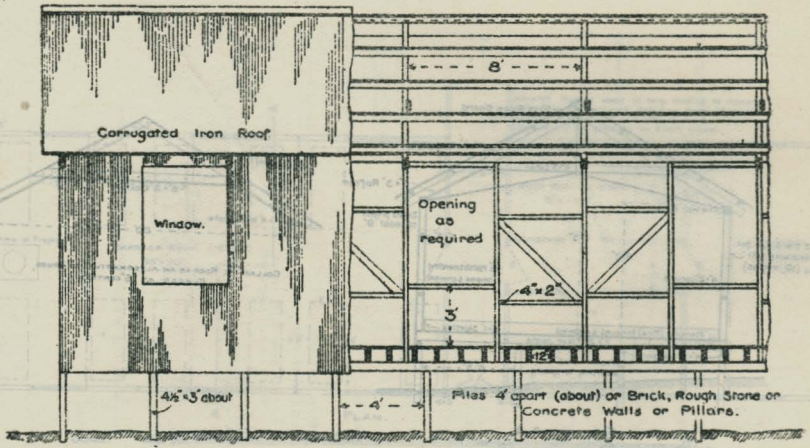

SECTION C.C.
CONCRETE FLOOR
LATRINE BLOCK.
SECTION D.D.
CONCRETE FLOOR
FEET 10 5 0 10 20 30 40 50 60 FEET

FIG. 4.



FRONT ELEVATION.

FIG. 5.

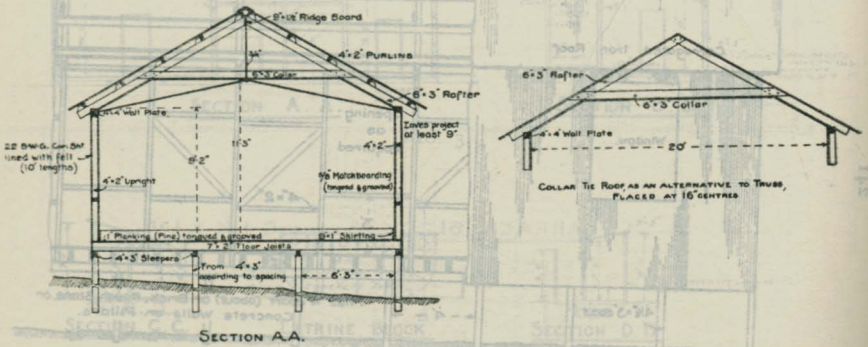

8"×1½" Ridge Board
4"×2" Purlins
6"×3" Collar
6"×3" Rafter
6"×4" Wall Plate
Eaves project at least 9"
4"×2"
11'5"
8'2"
22 S.W.G. Cor. Sht. lined with felt (10' lengths)
4"×2" Upright
⅝" Matchboarding (tongued & grooved)
1" Planking (Pine) tongued & grooved
6"×1" Skirting
7"×2" Floor Joists
4"×3" Sleepers
From 4"×3" according to spacing
6'3"
SECTION A.A.
6"×3" Rafter
6"×3" Collar
6"×4" Wall Plate
20'
COLLAR TIE ROOF AS AN ALTERNATIVE TO TRUSS, PLACED AT 16' CENTRES

FIG. 6.

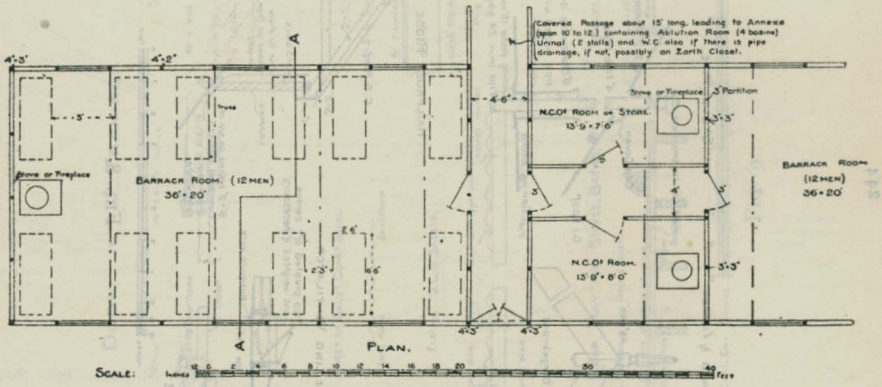

(Covered Passage about 15' long, leading to Annexe (span 10 to 12') containing Ablution Room (4 basins) Urinal (2 stalls) and W.C. also if there is pipe drainage, if not, possibly an Earth Closet.
4'-3"
4'-2"
Stove or Fireplace
BARRACK ROOM. (12 MEN)
36' × 20'
Stove or Fireplace
3' Partition
N.C.O's ROOM or STORE.
13'9" × 7'6"
BARRACK ROOM
(12 MEN)
36 × 20'
N.C.O's ROOM.
13'8" × 8'0"
4'-3"
4'-3"
PLAN.
SCALE:
Inches
Feet

FIG. 7.

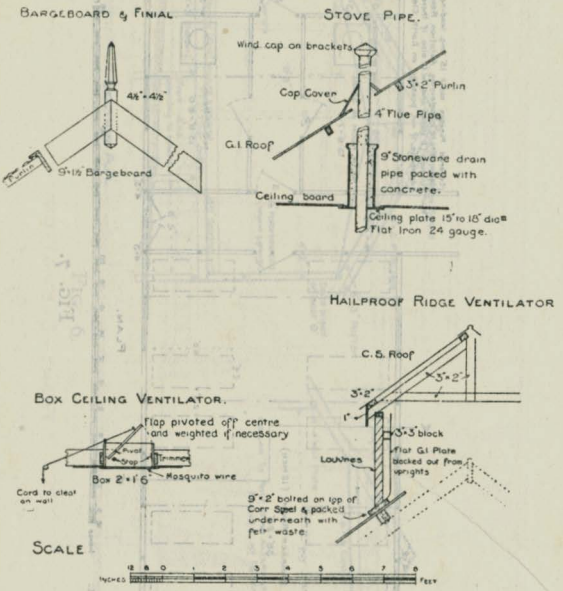

BARGEBOARD & FINIAL
4½"×4½"
9"×1½" Bargeboard
STOVE PIPE.
Wind cap on brackets
3"×2" Purlin
Cap Cover
4" Flue Pipe
G.I. Roof
9" Stonewave drain pipe packed with concrete.
Ceiling board
Ceiling plate 15" to 18" dia. Flat Iron 24 gauge.
HAILPROOF RIDGE VENTILATOR
C.S. Roof
3"×2"
3"×2"
1"
3"×3" block
Flat G.I. Plate bucked out from uprights
Louvres
9"×2" bolted on top of Corr Sheet & packed underneath with felt waste
BOX CEILING VENTILATOR.
Flap pivoted off centre and weighted if necessary
Rivet Strap
Trimmer
Box 2'×1'6"
Mosquito wire
Cord to cleat on wall
SCALE
INCHES
FEET

FIG. 8.

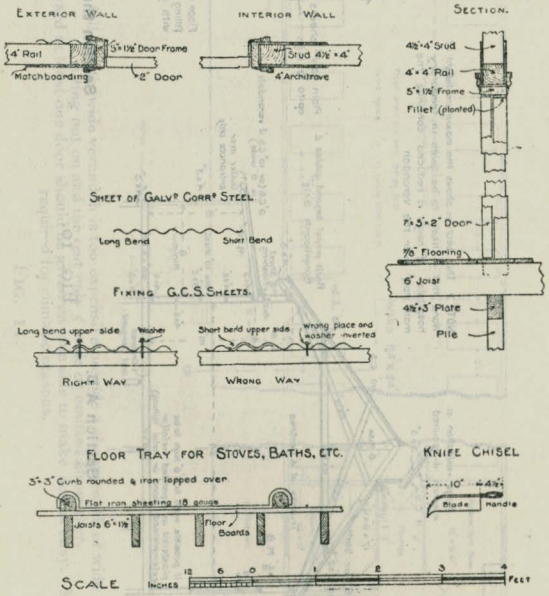
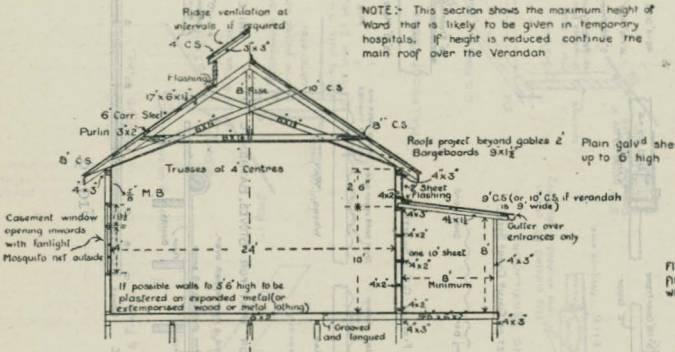

DOOR IN 4" FRAMING.
EXTERIOR WALL
INTERIOR WALL
SECTION.
4" Rail
5"×1½" Door Frame
Match boarding
2" Door
Stud 4½"×4"
4" Architrave
4½"×4" Stud
4"×4" Rail
5"×1½" Frame
Fillet (planted)
7"×5"×2" Door
⅞" Flooring
6" Joist
4½"×3" Plate
Pile
SHEET OF GALVD CORRD STEEL
Long Bend
Short Bend
FIXING G.C.S. SHEETS.
Long bend upper side
Washer
RIGHT WAY
Short bend upper side
Wrong place and washer inverted
WRONG WAY
FLOOR TRAY FOR STOVES, BATHS, ETC.
3"-3" Curb rounded & iron lapped over
Flat iron sheeting 18 gauge
Joists 6"×1½"
Floor Boards
KNIFE CHISEL
10"
4½"
Blade
Handle
SCALE
INCHES
FEET

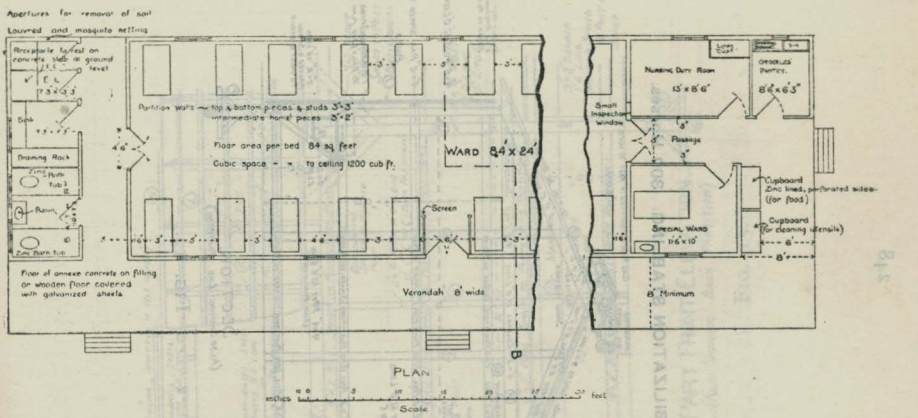
FIG. 9.



Section A.B.

Section through Bath Room

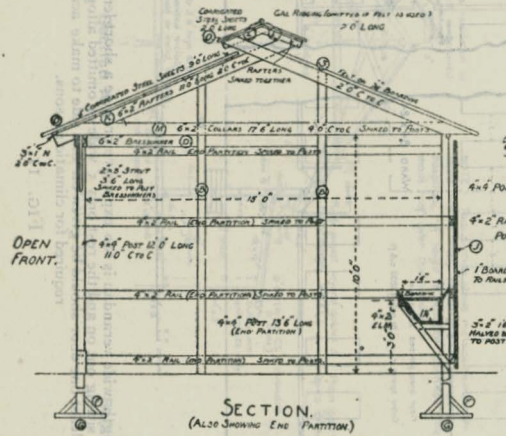
FIG. 10.



Note.—If a full-length wide verandah is too expensive provide a short length of wide verandah for sitting out on and the rest only 5′ wide or omitted altogether.
In a long ward at least one door should be given on one side to make access easy. More may be required for climatic reasons.

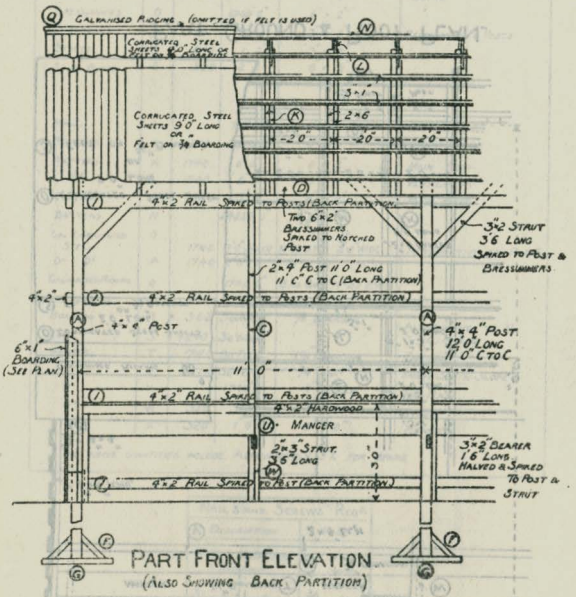
FIG. 11.

MOBILIZATION STABLING. 300 Horses.


CORRUGATED IRON SHEETS
CAL. RIDGING (SUPPLIED IF FELT IS USED)
2'0" LONG
RAFTERS SPACED TOGETHER
2'0" C TO C
6"x2" COLLARS 17'6" LONG 4'0" C TO C SPACED TO POSTS
6"x2" BRESSUMMER
4"x2" RAIL (END PARTITION) SPACED TO POSTS
2"x5" STRUT 3'6" LONG SPACED TO POST & BRESSUMMER
18'0"
4"x2" RAIL (END PARTITION) SPACED TO POSTS
OPEN FRONT.
6"x6" POST 12'0" LONG 11'0" C TO C
4"x2" RAIL (END PARTITION) SPACED TO POSTS
4"x6" POST 13'6" LONG (END PARTITION)
4"x2" RAIL (END PARTITION) SPACED TO POSTS
4"x4" POST 12'0" LONG
4"x2" RAIL SPACED TO POSTS
1" BOARDING SPACED TO RAILS (SEE PLAN)
3"x8" 18" LONG HALVED & SPACED TO POST & STRUT

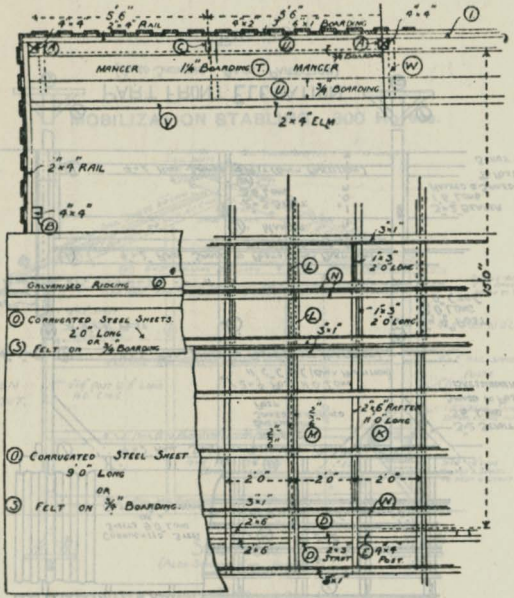
SECTION.
(ALSO SHOWING END PARTITION)

FIG. 12.


GALVANISED ROOFING (OMITTED IF FELT IS USED)
CORRUGATED STEEL SHEETS 6'0" LONG OR FELT ON 7/8 BOARDING
CORRUGATED STEEL SHEETS 9'0" LONG OR FELT ON 7/8 BOARDING
3"x1"
2"x6"
-20"-
4"x2" RAIL SPIKED TO POSTS (BACK PARTITION)
TWO 6"x2" BRESSUMMERS SPIKED TO NOTCHED POST
3"x2" STRUT 3'6" LONG SPIKED TO POST & BRESSUMMERS
2"x9" POST 11'0" LONG 11'0" C TO C (BACK PARTITION)
4"x2"
4"x2" RAIL SPIKED TO POSTS (BACK PARTITION)
4"x6" POST
4"x4" POST 12'0" LONG 11'0" C TO C
6"x1" BOARDING (SEE PLAN)
11'0"
4"x2" RAIL SPIKED TO POSTS (BACK PARTITION)
4"x2" HARDWOOD
MANGER
2"x3" STRUT 3'6" LONG
3"x2" BEARER 16" LONG HALVED & SPIKED TO POST & STRUT
4"x2" RAIL SPIKED TO FELT (BACK PARTITION)

PART FRONT ELEVATION.
(ALSO SHOWING BACK PARTITION)

FIG. 13.



PART GROUND & ROOF PLAN.

FIG. 14

SCHEDULE OF MATERIALS.

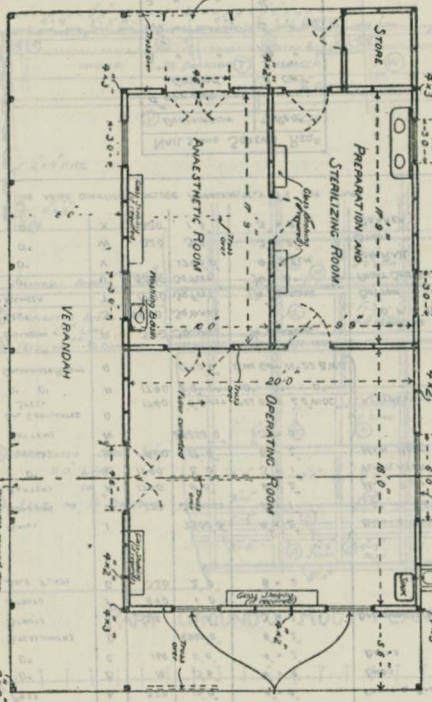
DESCRIPTION	IDENTIFICATION LETTER	No	LENGTH OR AREA	SCANTLING	REMARKS
POST	A	320	12'0"	4" x 4"	FRONT & BACK
Do	B	16	13'6"	4" x 4"	ENDS
Do	C	160	11'0"	4" x 2"	BACKS
BRESSUMMERS	D		6900'0"	6" x 2"	
STRUTS	E	316	3'6"	3" x 2"	BRESSUMMERS & POSTS
STRUTS	F	640	1'0"	3" x 2"	
SOLE PLATE	G	320	2'0"	6" x 2"	
RAILS	I		7500'0"	4" x 2"	BACK & ENDS
BOARDING	J	1250	SQUARES	6" x 1"	Do Do
RAFTERS	K	1740	11'0"	6" x 2"	MAIN ROOF
Do	L	1740	2'0"	3" x 1"	VENTILATOR
COLLARS	M	420	17'6"	6" x 2"	MAIN ROOF
BATTENS	N		24250'0"	3" x 1"	
GAL CORRUGATED STEEL	O	1740	9'0" SHEET	No 22 BWG 2'2" WIDE	ALTERNATIVE TO R & S
Do Do	P	1740	2'0" Do	Do Do Do	
GALVANISED RIDGING OR	Q		1740'0"	15ins GIRT No 22 BWG	
BOARDING	R	382	SQUARES	7/8" BOARDING	ALTERNATIVE TO N. O. P. & Q
FELT	S	4240	SQ YARDS		
MANGER	T	1740	SQ FEET	1¼ BOARDING	BOTTOM
Do	U	5500	SQ FEET	7/8 Do	FRONT SIDE & SLOPE
Do	V		1740'0"	4" x 2 ELM	TOP RAIL.
Do	W	320	3'6"	3" x 2"	STRUT
Do	X	320	1'6"	3" x 2"	BEARER

THE ABOVE QUANTITIES INCLUDE APPROXIMATELY 5% FOR SPARE

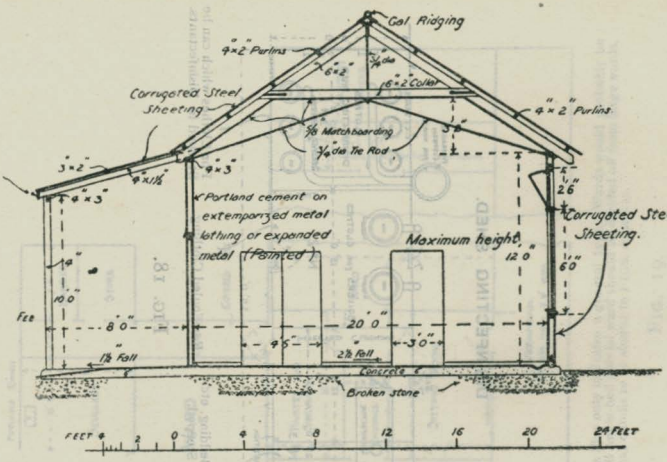
NAILS AND SCREWS REQD	
DESCRIPTION	REQD
4" Wire Nails, Iron Grooved	3 CWT
3" " "	¾ "
2½" " "	5 "
2" " "	¼ "
3" Gal Coach Screws	160 Gross
Felting Nails 3lbs per 1000	1¾ CWT

FIG. 15.

Verandah ramped down for wheeled stretcher.


OPERATING ROOM.
Note.- Most lighting by large North light
STORE
PREPARATION AND STERILIZING ROOM
ANAESTHETIC ROOM
OPERATING ROOM
VERANDAH
Sink
Table
Teak
Teak over
Teak
Teak
Teak
Teak over
Verandah ramped down
Teak over
Teak
Teak
Teak
Teak

Gutters over entrances only.



SCALE.

SECTION AB.

Windows:—Mosquito proof.
Floor:—6" concrete 1" cement rendering.
Drainage:—To be specially dealt with.

FIG. 17.

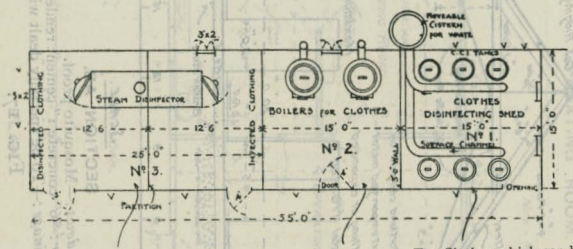
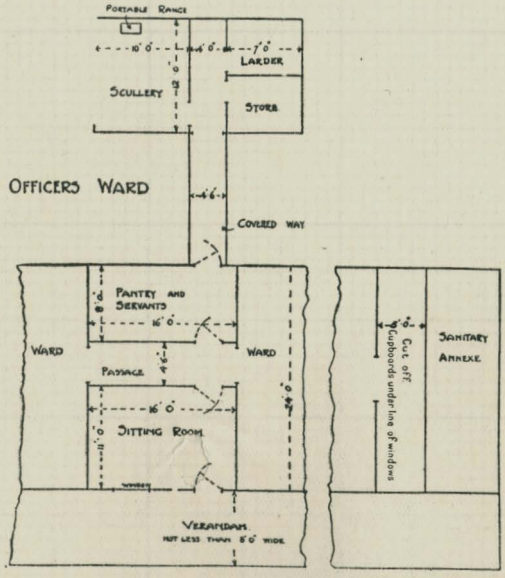
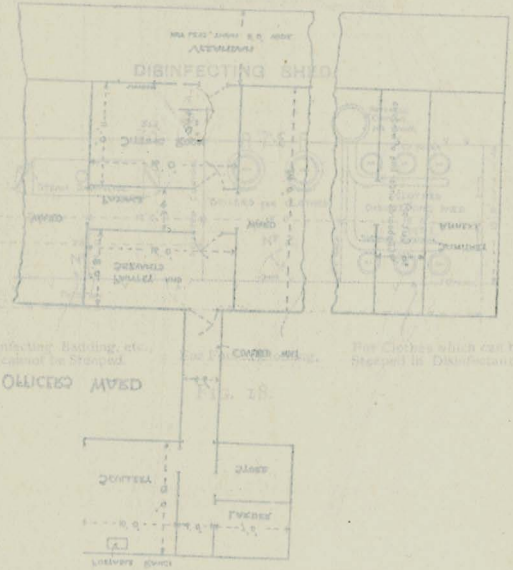

DISINFECTING SHED.
Disinfected Clothing
Steam Disinfector
Infected Clothing
Boilers for Clothes
Clothes Disinfecting Shed
No 3.
No 2.
No 1.
Partition
Door
Sewage Channel
For Disinfecting Bedding, etc., that cannot be Steeped.
For Fouled Clothing.
For Clothes which can be Steeped in Disinfectants.

FIG. 18.



This Outline Plan only indicates a general type. Wards would probably be small. A small single-bed special ward should be divided off from large wards. Constructional details to be similar to FIGS. 10 and 11.

FIG. 19.


DISINFECTING SHED
OFFICERS MESS

SECTION IX.

MILITARY ROADS.

Traction on Roads.

Each horse can exert at a walk, continuously, at the rate of 3 to 4 miles an hour, a pull of 112lbs. average.

The pull or resistance of a good levelled road = 1 in 30 of gross weight moved.

On a gradient of $\frac{1}{A}$, the force required to move a load $= W \times \left(\frac{1}{A} \pm \frac{1}{30}\right)$ when W is gross load. On badly metalled rough roads the resistance is sometimes as much as 1 in 10 gross load.

A straight road is better for artillery, even if steep, up to 1 in 10, than a winding road.

On hill roads the re-entering angles should always be widened for artillery.

A winding road may be better, if the gradients are easy, for transport vehicles.

Generally, for long lines of main communication, make a ruling gradient 1 in 20. Under very special circumstances it may be 1 in 10 for distances of 200′.

Survey of Road.

If good maps of the country exist it is easy to lay out a good line of road on paper, go over it on the ground, and alter according to circumstances. But if, as will usually be the case, long lines of road have to be made in uncivilized countries, a rough reconnaissance should be

made with aneroid and watch and prismatic compass. The rate and direction of marching, the times of halting and of taking any observations, should be noted; known points should be observed for interpolating, and the aneroid readings should be taken at every point where the ground evidently changes inclination. In this way a fairly accurate plan and section of the route traversed can be plotted. Heights may be checked occasionally by ascertaining temperature at which water boils. The saddles between mountains should be carefully reconnoitred. Outlying spurs or hillocks may often be utilized for working in an easy grade without having recourse to zigzags.

Hill Roads.

In laying out the road, work from decisive points, *e.g.*, the saddle of a hill range, the crossing of a river. From these points run a trial line with the ruling gradient, and see where it intersects difficult ground. Mark those difficult points, and shift the location there to the best advantage, readjusting the gradients to see how the whole works in. With a little management the difficult places may often be worked in easily.

In laying out a line along the side of steep mountains, the clinometer should be fixed at the ruling gradient and observations taken from some commanding point. Various points on the line of this gradient should then be marked. The road, if constructed to pass through these points and following the sinuosities of the ground, will obviously be easier than the ruling gradient in some parts, and nowhere more difficult.

Don't continually work up to the ruling gradient; on long grades, even if easy ones, put in, at frequent intervals, flat pieces 40 to 50 yards long. Wheeled traffic must halt, and if there is no flat piece the road will be littered with big stones, which have been used to scotch up the wheels.

In wooded countries, observations should be taken from the highest trees. When the line is determined on, it should be marked by pegs or piles of stones, or by cutting

a path. In woods a path should be cut, and the biggest trees marked.

Bridge Approaches.

In laying out a road with many bridges, select the bridge sites *first*, and lay out the centre line of the bridge before fixing the direction of the approaches. The approaches should be in continuation of the line of the bridge for at least 20 yards on either bank. The neglect of this may lead to accidents from vehicles upsetting, etc., and cause serious interruption to traffic. If it is proposed to construct a bridge near a ford, leave approaches to the ford undisturbed, so as to admit of an alternative route.

Turning Places.

Turning places on a zigzag road should be very wide and quite flat. No zigzag should ever have an angle, but always an inner curve, if possible not less than a circle of 3′ radius, or on the outer a curve of 50′ radius. There should also be a masonry wall, no matter how roughly built, around the curve to prevent strings of animals trying to cut off the corner, leading to blocks of traffic and endless delays (see *Fig.* 1).

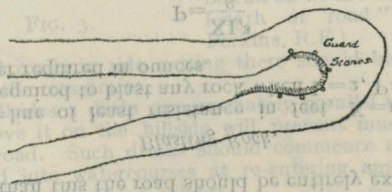


FIG. 1.

CONSTRUCTION.

In carrying out road work by infantry working parties, detailed instructions, illustrated, if necessary, with

diagrams, should be given to the officers, who will often give valuable suggestions.

A road may be constructed along a slope partly in cutting, partly in bank, when the natural slope of the ground does not exceed 1 in 2. If the natural slope is greater than this the road should be entirely excavated.

Blasting Rock.

If L=line of least resistance in feet, X=number of ounces required to blast any rock when L=2, P=quantity of powder required in ounces.

Then $$P=\frac{XL^3}{8}$$

when X=4 oz., $P=\frac{L^3}{2}$, which is a fair general rule.

Another rough rule is 1 oz. for every foot bored. This gives good results for mountain limestone. L should not exceed half the depth of hole. In small blasts 1lb. of powder will loosen about $4\frac{1}{2}$ tons.

With all explosives some experiments should be made in the rock to be attacked. Plastic explosives, such as dynamite and gelatine, are more than twice as strong as gunpowder, and are more adapted for use in blast-holes than guncotton. The latter is very useful in breaking boulders without boring or tamping.

The rate of progress in boring blast-holes varies, not only with the nature of the rock, but with the inclination of the hole. It is best to make the holes vertical. The usual width is $1\frac{1}{2}''$. Natives of eastern countries work better with jumpers than boring bars, but Europeans *vice versâ*. The rate of progress may be taken at 1′ *per hour* for 2 men. With steel boring bars and hammers, 3 men, with a 2″ bar, should bore 8′ of granite in 10 hours.

In tamping, a copper-tipped rammer is used to press the material used over the charge. Water may be used with gelatine, or dynamite if in a waterproof bag. For preparation and placing of charges see Section V.

"Irish bridges," *Fig.* 2, are often very useful for cross draining in military roads. They consist of paving with boulders or blocks laid on edge, so that water can flow over them without cutting up the road or impeding the traffic. It is advisable to give a curtain wall at the down-stream end.

FIG. 2.

Where flat stones are procurable, good road culverts up to 4′ width can be built dry, *i.e.*, without mortar of any sort, by corbelling (see *Fig.* 3) This plan is often adopted in hill roads in India.

FIG. 3.

"Cross drainage along all hill sections should be given at every 150′, and at every natural depression in the road. On a zigzag formation the water should be run off at the end of every length of road" (General Perkins, R.E.).

On all roads in side cutting there should be an inside drain with cross drains.

On hillsides a drain approximately parallel to the road and above it on the hillside will prevent much damage to the road. Such drains should commence at salients, and lead into watercourses at re-entering angles, where there will usually be a culvert.

These drains should be from 6′ to 8′ from the edge of the slope, and the soil from the excavation should be thrown on the road side of the drain, and spread, otherwise it will be washed into the drains. These drains should be made large. The longer the distance from the top of the slope, the more these catch-water drains will

be needed. If the distance is very short they will not be needed at all.

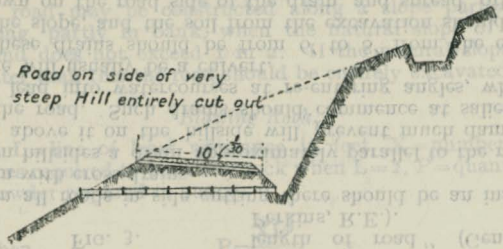


FIG. 4.

Retaining Walls.

The rules for construction of retaining walls are as follows :—The back of the wall should be vertical, the front face with a batter 4 in 1, the courses of masonry should be normal to the batter. The width of wall at top should be 2′ for walls above 4′ in height, 1½′ for less than 4′. In soft soils both faces may batter, inner 6 in 1.

It must be remembered that all stone retaining walls on mountain roads should be built with courses *longitudinally horizontal;* the ground should be stepped, if necessary, for the foundations. The largest stones should always be used.

In the construction of retaining walls of stone, the following is the rule laid down by General Perkins, R.E. :—

" There is to be a line of through bond, consisting of one or several stones put together as shown in *Fig.* 5, at every

FIG. 5.

5′ in every course of masonry. The bond stone should break joint in alternate courses. If possible, use stones of lengths equal to the thickness of the wall. If these are not procurable, the long flat stones should be set aside, and these should be laid carefully end on to one another. . . . In the next course covering stones are to be laid carefully over the joints first, and then the full course built."

In a wooded country, timber revetments may be built. In this case long logs should be laid at right angles to the face of the structure at 5′ intervals, longitudinally, as in a fascine revetment.

Metalled Road.

On level ground run drain on both sides, throw earth into middle. Width for military purposes—16′ if possible; minimum, 14′; in very hilly countries, 12′ may be permitted. The stones used for metalling should be capable of passing through 2″ ring in every direction, and small stuff (not smaller than will pass through a ¾″ screen) should be freely used, but not earth. The centre should be convex, falling about 1 in 30 to the sides. The metalling should be in two 3″ layers, each rolled to 2″. This is good enough for a military road on fairly dry soil. Gravel should not be less than ¾″ or more than 1½″. Gravel, however, will never bind so as to make a good metalled road. In all cases of the consolidation of a metalled road, water and fine gravel, sand, etc., for binding purposes should be used, and the surface well rolled or rammed.

Roads in Wet Soil.

If soil is very wet use cross drains, lay hurdles or fascines across and branches of trees with thick ends towards edge of road, then a layer of sods or hard clay, then metalling. A successful military road was made over a swamp by cutting ditches at right angles to the road, about 4′ wide, leading into a broad drain, which took off all the water

to a lower level. The road was built up with sods and brushwood to a height of 4′ above the marsh. The cross ditches were about 20 yards apart. Even though it may not be necessary to make such elaborate drainage works as this, some cross drainage (with drain-pipes or rough stonework) is generally advisable in wet situations.

Corduroy Roads.

The following remarks on roads in well-wooded countries are extracted from *Wolseley's Pocket Book* :—

Corduroy roads are made by laying young trees of from 6″ to 12″ diameter side by side and close together, to form the surface. A pole about 6″ by 6″ should be pinned with spikes or trenails along their outer surface, to keep them in position. . . . It is most desirable to adze away the logs along the wheel track, so that the wheels may pass over an even surface.

Plank Roads.

When 3″ planks are to be had they form very good roads for military purposes. For a 16′ road the planks should be laid on four sleepers, the outer ones 5″ by 5″, the inner ones 6″ by 2″, laid on the flat side . . . sunk to a level with the surface. The junction of one row of sleepers should not be opposite that of other rows, and a piece of plank 12′ long should be placed under each junction. The spikes used should be 5″ long (100 spikes = 22lbs.) with chisel-shaped edges, which are to be driven across the fibre; wooden spikes can be used if iron is not to be had. If there is plenty of material at hand it is a good plan to spike a piece of scantling 5″ by 5″ down the centre (as a wheel guide). The edge of the planking should be irregular, so that if a wheel goes off it may be got on again without difficulty.

MAINTENANCE.

As military roads will have to bear constant traffic, *repair* must be arranged for. Maintenance gangs, 2 or 3 men for every 4 miles, will often be necessary. Hammers

(3lbs. in weight, with handle 2½′ long, so as to work standing, or of 1½lbs. weight with handles 18″ to 2′ long, to work sitting) should be provided in sufficient quantities to replace breakages, and bags or barrows for collecting metal are also required. A cubic yard of good broken stone is sufficient for a rod super. of road. The mud and dirt should be removed and ruts filled in. The drainage must be constantly attended to.

to a lower level. The road was built up with sods and brushwood to a height of 4' above the marsh. The cross ditches were about 20 yards apart. Even though it may not be necessary to make such elaborate drainage works as this, some cross drainage (with drain-pipes or rough stonework) is generally advisable in wet situations.

Corduroy Roads.

The following remarks on roads in well-wooded countries are extracted from *Wolseley's Pocket Book* :—

Corduroy roads are made by laying young trees of from 6" to 12" diameter side by side and close together, to form the surface. A pole about 6" by 6" should be pinned with spikes or trenails along their outer surface, to keep them in position. It is most desirable to adze away the logs along the wheel track, so that the wheels may pass over an even surface.

Plank Roads.

When 3" planks are to be had they form very good roads for military purposes. For a 16' road the planks should be laid on four sleepers, the outer ones 3" by 3", the inner ones 6" by 3", laid on the flat side sunk to a level with the surface. The junction of one row of sleepers should not be opposite that of other rows, and a piece of plank 12' long should be placed under each junction. The spikes used should be 5" long (100 spikes = 22lbs.) with chisel-shaped edges, which are to be driven across the fibre; wooden spikes can be used if iron is not to be had. If there is plenty of material at hand, it is better to adze a piece of scantling 5" by [illegible] for the edge of the road to rest on, than to depend on planks thin pins not to split. The collection of water is injurious to a road. A cross drain every 10 feet. Best to taper off the ends of

SECTION X.

RAILWAYS.

Power of Locomotives.

T = tractive effort in lbs.
P = boiler pressure in lbs. per square inch.
C = diameter of cylinder in inches in simple engines.
C_h = ,, of high pressure cylinder in compound engines.
C_l = ,, of low pressure cylinder in compound engines.
S = stroke in inches.
D = diameter of driving wheel in inches.
K = a constant = ·85 for 2-cylinder simple engines.
1·7 for 4-cylinder simple engines.
·6 for 2-cylinder compounds.
1·2 for Mallet 4-cylinder compounds.

$T = \frac{KPC^2S}{D}$ for simple engines .....(i.).

$T = \frac{KPC_h{}^2S}{D}$ for 2-cylinder compounds and Mallet 4-cylinder compounds....(ii.).

$T = \frac{S \times P}{D}\left(\frac{2}{3}C_h{}^2 + \frac{1}{4}C_l{}^2\right)$ for 4-cylinder compounds (non-Mallet type)....(iii.).

Engines fitted with superheaters can start the load as calculated from their dimensions by the formulæ above.

But for the loads they will haul these figures must be reduced 10 per cent. The tractive efforts at starting, as found above, must further be reduced as the speed rises by taking—

At 20 miles per hour 75% of calculated tractive effort.
" 30 " " 50% " " "
" 50 " " 30% " " "

The tractive power of a locomotive, however, is often limited by the *adhesion* of the driving wheels to the rails. This adhesion is equal to the weight on the driving wheels multiplied by a co-efficient (see below) depending on weather.

The average adhesion is $\frac{1}{7}$ weight on driving wheels.

Adhesion per Ton of Load on Driving Wheels.

When the rails are very dry ..	600lbs. per ton.
When the rails are very wet ..	550 " " "
Ordinary English weather	450 " " "
Misty weather, greasy rails	300 " " "
Frosty or snowy weather	200 " " "

In coupled engines the adhesive force is due to the load on all wheels coupled to the driving wheels.

The total resistance of a train is the sum of the resistances due to—

(*a*). Gradients, calculated in total weight of engine and train.
(*b*). The friction, etc., of the engine.
(*c*). The friction, etc., of the train on the straight.
(*d*). Additional resistance of engine and train on curves.
(*a*). The *resistance due to gradients* on a railway is :—

The force F required to move one ton up a slope of 1 in $n = \frac{1 \text{ ton}}{n}$; or resistance in lbs.

$$= \frac{2240}{n} \times \text{no. of tons in the train} \ldots\ldots \text{(iv.)}.$$

Table of Gradients.

Gradient of 1 in	20	25	30	35	40	45	50	60	70	80	90	100
Rise in feet per mile ..	264	211	176	151	132	117	105	88	75	66	58	52
Resistance in lbs. per ton	112	89½	74½	64	56	50	45	38	32	28	25	22

(*b*). R_1 = the total resistance on the straight of an engine with tender in lbs. per ton of total weight.
M = speed in miles per hour.

For 4-coupled engines (79″ driving wheels)

$$R = 8{\cdot}5 + {\cdot}1M + {\cdot}004M^2.$$

For 6-coupled engines (79″ driving wheels)

$$R = 10 + {\cdot}125M + {\cdot}004M^2.$$

For 8-coupled engines (56″ driving wheels)

$$R = 13 + {\cdot}5M + {\cdot}004M^2.$$

.....(v.).

(*c*). R_2 = the resistance in lbs. per ton of the gross load of the train, excluding the engine, on the straight.
For 4-wheeled trucks

$$R_2 = 3{\cdot}6 + {\cdot}07M + {\cdot}0027M^2.$$

For bogie coaches or wagons

$$R_2 = 3{\cdot}6 + {\cdot}03M + {\cdot}0022M^2.$$

.....(vi.).

(*d*). The additional resistance to be added to the above for curvature, in lbs. per ton of weight, is :—
For 4-wheeled or bogie cars, 0·7lb. per degree of curvature.
For engines, 1·4lb. per degree of curvature.

Increase these figures by 50 per cent. for 6-wheeled coaches or 8-coupled engines.

In comparing tractive efforts with train resistances found by formulæ (i.) to (v.) it is advisable to allow a margin of 15 to 20 per cent. in favour of the engine to allow for accidents, bad weather, etc.

Ratio of Wheel Base to Curves.

R = min. radius of curve in feet.
W = max. wheel base in feet.
G = gauge of line.

Then $R = 9\,W.G.$ ..... (vii.).

For 4′ 8½″ gauge curves of less than 400′ radius are undesirable.

Fuel and Water.

On English railways, 4′ 8½″ gauge, the following may be taken as a fair allowance for fuel consumption with average coal. It includes the amount required for lighting up, shunting, etc., and a margin to cover the increase due to engines being only in moderately good order :—

For express passenger trains (40—50 m.p.h.), ·15lb. per ton mile.
For troop and goods trains (calculated on gross weight of engine and train), ·2lb. per ton mile.

1 ton of good coal = 2¼ tons of good dry wood.
Green wood should never be used.

In calculating water supplies allow 10lbs. of water (1 gallon) per lb. of coal as found above for all purposes. Superheater and compound engines will use 20 to 30 per cent. less than this.

Superelevation of Rails.

Half an inch for each degree of the curvature is a good rule for 4′ 8½″ gauge (*i.e.*, for a 4° curve give 2″), or

$E = \frac{V^2G}{32{\cdot}2R}$ where E = elevation in inches, V = velocity in feet per second, G = gauge in inches, R = radius in feet.

Another practical rule for superelevation is :—

Let V = max. velocity of trains in feet per second, G = gauge of the railway in feet, C = length of a chord in feet whose versed sine will give at the centre the required elevation ; then

$$C = \tfrac{1}{2} V \sqrt{G}.$$

$\sqrt{G}$ for 4′ 8½″ gauge = 2·17.

Make a chord = C, and stretch it on the inner side of the rails ; the distance of the rails from it at its middle will give the proper elevation, no matter what the radius may be.

Curves.

Table of Radii in feet corresponding to curves with 100′ *chords. The angle given is the angle at the centre, i.e., twice the deflection angle.*

Angle.	Rad.	Angle.	Rad.	Angle.	Rad.
° ′		° ′		° ′	
0 30	11459	6 30	882	12 30	459
1 0	5730	7 0	819	13 0	441
1 30	3820	7 30	764	14 0	410
2 0	2865	8 0	716	15 0	383
2 30	2292	8 30	674	16 0	359
3 0	1910	9 0	637	17 0	338
3 30	1637	9 30	603	18 0	319
4 0	1433	10 0	573	19 0	302
4 30	1274	10 30	546	20 0	287
5 0	1146	11 0	521	21 0	274
5 30	1042	11 30	499	22 0	262
6 0	955	12 0	478	23 0	250

The versed sine in inches of a chord 61′ long = angle of the curve in degrees.

Useful Formulæ in Railway Curves (*see Fig.* 1).

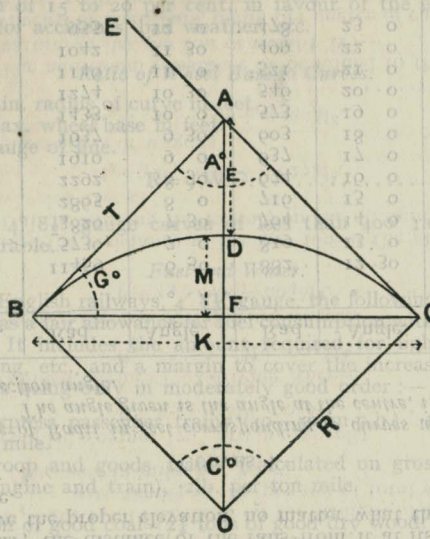


FIG. 1.

Symbols used in formulæ and tables :—

BOC = BAE = C°
BAC = A°
ABC = G° = ½C°
BDC, length of curve = L
AB = AC = T
AD = E
BC = K
DF = M

Number of chords of 100′ in curve = N.
Angle of curve with 100′ chords = a.
N.B.—$d°$ = central angle subtending chord K = 10′.
$D° = 10 \times d°$, or angle subtending 10 chords of 10′ each.

$$R = \frac{\frac{K}{2}}{\sin \frac{1}{2}d}.$$

$$T = R \tan \frac{C}{2}$$
$$= R \cot \frac{A}{2}$$
$$= R \tan G.$$

$$E = R \left(\operatorname{cosec} \frac{A}{2} - 1\right)$$
$$= R \left(\sec G - 1\right)$$
$$= T \tan \frac{C}{4}$$
$$= M \frac{1}{\cos \frac{1}{2}C}.$$

$$K = 2R \sin \frac{C}{2}$$
$$= 2R \cos \frac{A}{2}$$
$$= 2R \sin G$$
$$= 2T \cos \frac{C}{2}$$
$$= 2M \cot \frac{C}{4}$$

$$M = R\left(1 - \sin \frac{A}{2}\right)$$
$$= R(1 - \cos A)$$
$$= R \operatorname{vers} \frac{C}{2}$$
$$= E \cos \frac{C}{2}.$$

If C be expressed in minutes—

$$R = \frac{1719 \times 100}{\frac{1}{2}C} \text{ for 100′ chords}$$

$$N = \frac{180 - A}{a} = \frac{5400 - \frac{A}{2}}{\frac{1}{2}C}.$$

If any abscissa y be measured from C or B towards A, then the offset x, measured at right angles to the tangent $= R - \sqrt{R^2 - y^2}$.

The following table gives the values of L, T, E, K, and M for various values of the central angle C *for a 4° curve, i.e.*, with radius $= 1432'$. For any other curve the values can be at once obtained from the table by considering the relative value of that curve with a 4° curve, the values being in the inverse ratio of the degrees of curvature. Thus the values for a 2° are twice, and for an 8° curve half, those given in the table :—

Table of Values of L, T, etc., for a 4° Curve.

C° BOC or BAE	A° BAC	G° ABC	L Length of Curve.	T Length of Tangent.	E Length of Versed Sine.	K Length of Chord.	M Length of Central Offset.	Tan $\frac{C}{2}$	Sec. $\frac{C}{2}$
		° ′							
1	179	0·30	25·00	12·50					
2	178	1·0	50·00	25·00	0·138	49·98	0·138	·017	1·00
3	177	1·30	75·00	37·50	0·49	74·99	0·49	·026	
4	176	2·0	100·00	50·02	0·87	99·97	0·87	·035	1·00
5	175	2·30	125·00	62·54	1·36	124·96	1·36	·044	
6	174	3·0	150·0	75·06	1·96	149·93	1·96	·052	1·001
7	173	3·30	175·0	87·60	2·67	174·89	2·67	·061	1·002
8	172	4·0	200·0	100·16	3·49	199·83	3·48	·070	1·002
9	171	4·30	225·0	112·73	4·43	224·76	4·41	·079	1·003
10	170	5·0	250·0	125·31	5·47	249·68	5·45	·087	1·004
11	169	5·30	275·0	137·92	6·62	274·57	6·59	·096	1·005
12	168	6·0	300·0	150·55	7·89	299·45	7·84	·105	1·005
13	167	6·30	325·0	163·20	9·26	324·30	9·20	·114	1·006
14	166	7·0	350·0	175·87	10·75	349·13	10·67	·123	1·007
15	165	7·30	375·0	188·57	12·36	373·93	12·25	·131	1·009
16	164	8·0	400·0	201·31	14·07	398·70	13·94	·140	1·010
17	163	8·30	425·0	214·07	15·90	423·46	15·73	·149	1·011
18	162	9·0	450·0	226·87	17·85	448·15	17·63	·158	1·012

TABLE OF VALUES OF L, T, ETC., FOR A 4° CURVE.—*Cont.*

C° BOC or BAE	A° BAC	G° ABC	L Length of Curve.	T Length of Tangent.	E Length of Versed Sine.	K Length of Chord.	M Length of Central Offset.	Tan $\frac{C}{2}$	Sec $\frac{C}{2}$
		° ′							
19	161	9·30	475·0	239·70	19·91	472·82	19·64	·167	1·014
20	160	10·0	500·0	252·57	22·09	497·46	21·76	·176	1·015
21	159	10·30	525·0	265·47	24·39	522·06	23·98	·185	1·017
22	158	11·0	550·0	278·43	26·81	546·62	26·31	·194	1·019
23	157	11·30	575·0	291·42	29·34	571·14	28·75	·203	1·020
24	156	12·0	600·0	304·46	32·00	595·62	30·30	·212	1·022
25	155	12·30	625·0	317·55	34·77	620·05	33·95	·222	1·024
26	154	13·0	650·0	330·69	37·67	644·44	36·71	·231	1·026
27	153	13·30	675·0	343·88	40·70	668·77	39·57	·240	1·028
28	152	14·0	700·0	357·13	43·85	693·05	42·54	·249	1·030
29	151	14·30	725·0	370·44	47·12	717·23	45·62	·259	1·033
30	150	15·0	750·0	383·81	50·53	741·46	48·80	·268	1·035
31	149	15·30	775·0	397·24	54·06	765·58	52·09	·277	1·038
32	148	16·0	800·0	410·73	57·72	789·64	55·48	·287	1·040
33	147	16·30	825·0	424·29	61·52	813·64	58·98	·296	1·043
34	146	17·0	850·0	437·92	65·44	837·58	62·59	·306	1·046
35	145	17·30	875·0	451·63	69·51	861·46	66·29	·315	1·048
36	144	18·0	900·0	465·41	73·71	885·27	70·10	·325	1·051

TABLE OF VALUES OF L, T, ETC., FOR A 4° CURVE.—*Cont.*

C° BOC or BAE	A° BAC	G° ABC	L Length of Curve.	T Length of Tangent.	E Length of Versed Sine.	K Length of Chord.	M Length of Central Offset.	Tan $\frac{C}{2}$	Sec $\frac{C}{2}$
		° ′							
37	143	18·30	925·0	479·27	78·05	909·01	74·02	·335	1·054
38	142	19·0	950·0	493·21	82·53	932·68	78·09	·344	1·058
39	141	19·30	975·0	507·24	87·16	956·29	82·16	·354	1·060
40	140	20·0	1000·0	521·35	91·92	979·82	86·38	·364	1·064
41	139	20·30	1025·0	535·55	96·84	1003·27	90·71	·374	1·068
42	138	21·0	1050·0	549·84	101·90	1026·65	95·13	·384	1·071
43	137	21·30	1075·0	564·23	107·12	1049·95	99·67	·394	1·075
44	136	22·0	1100·0	578·72	112·49	1073·17	104·30	·404	1·078
45	135	22·30	1125·0	593·32	118·02	1096·31	109·03	·414	1·082
46	134	23·0	1150·0	608·02	123·70	1119·36	113·86	·424	1·086
47	133	23·30	1175·0	622·82	129·54	1142·33	118·80	·435	1·090
48	132	24·0	1200·0	637·74	135·55	1165·22	123·83	·445	1·095
49	131	24·30	1225·0	652·78	141·73	1188·01	128·97	·456	1·099
50	130	25·0	1250·0	667·94	148·07	1210·71	134·20	·466	1·103
51	129	25·30	1275·0	683·22	154·60	1233·32	139·53	·477	1·108
52	128	26·0	1300·0	698·62	161·29	1255·84	144·96	·488	1·113
53	127	26·30	0325·0	714·16	168·16	1278·26	150·49	·499	1·117
54	126	27·0	1350·0	729·84	175·22	1300·59	156·12	·509	1·122

TABLE OF VALUES OF L, T, ETC., FOR A 4° CURVE.—*Cont.*

C° BOC or BAE	A° BAC	G° ABC	L Length of Curve.	T Length of Tangent.	E Length of Versed Sine.	K Length of Chord.	M Length of Central Offset.	Tan $\frac{C}{2}$	Sec $\frac{C}{2}$
		° ′							
55	125	27·30	1375·0	745·66	182·46	1322·81	161·84	·521	1·127
56	124	28·0	1400·0	761·62	189·90	1344·94	167·66	·532	1·132
57	123	28·30	1425·0	777·73	197·51	1366·96	173·58	·543	1·138
58	122	29·0	1450·0	793·99	205·34	1388·88	179·59	·554	1·143
59	121	29·30	1475·0	810·41	213·36	1410·69	185·70	·566	1·149
60	120	30·0	1500·0	827·00	221·59	1432·40	191·90	·577	1·155
61	119	30·30	1525·0	843·74	230·03	1454·00	198·20	·589	1·160
62	118	31·0	1550·0	860·67	238·68	1475·48	204·59	·601	1·167
63	117	31·30	1575·0	877·77	247·55	1496·85	211·07	·613	1·173
64	116	32·0	1600·0	895·06	256·65	1518·11	217·65	·625	1·179
65	115	32·30	1625·0	912·53	265·98	1539·25	224·32	·637	1·186
66	114	33·0	1650·0	930·21	275·54	1560·28	231·08	·649	1·192
67	113	33·30	1675·0	948·08	285·34	1581·19	237·94	·662	1·199
68	112	34·0	1700·0	966·16	295·38	1601·97	244·88	·674	1·206
69	111	34·30	1725·0	984·46	305·68	1622·64	251·92	·687	1·213
70	110	35·0	1750·0	1002·98	316·23	1643·18	259·04	·700	1·221
71	109	35·30	1775·0	1021·72	327·05	1663·60	266·26	·713	1·228
72	108	36·0	1800·0	1040·70	338·14	1683·88	273·56	·726	1·236

TABLE OF VALUES OF L, T, ETC., FOR A 4° CURVE.—*Cont.*

C° BOC or BAE	A° BAC	G° ABC	L Length of Curve.	T Length of Tangent.	E Length of Versed Sine.	K Length of Chord.	M Length of Central Offset.	Tan $\frac{C}{2}$	Sec $\frac{C}{2}$
		° ′							
73	107	36·30	1825·0	1059·92	349·50	1704·04	280·95	·740	1·244
74	106	37·0	1850·0	1079·39	361·15	1724·08	288·43	·753	1·252
75	105	37·30	1875·0	1099·12	373·10	1743·98	296·00	·767	1·260
76	104	38·0	1900·0	1119·11	385·34	1763·74	303·65	·781	1·269
77	103	38·30	1925·0	1139·38	397·90	1783·38	311·39	·795	1·278
78	102	39·0	1950·0	1159·93	410·75	1802·87	319·21	·810	1·287
79	101	39·30	1975·0	1180·78	423·94	1822·23	327·12	·824	1·296
80	100	40·0	2000·0	1201·93	437·46	1841·45	335·11	·839	1·305
81	99	40·30	2025·0	1223·38	451·33	1860·53	343·19	·854	1·315
82	98	41·0	2050·0	1245·17	465·54	1879·47	351·35	·869	1·325
83	97	41·30	2075·0	1267·28	480·13	1898·27	359·59	·885	1·335
84	96	42·0	2100·0	1289·74	495·08	1916·92	367·92	·900	1·346
85	95	42·30	2125·0	1312·55	510·42	1935·43	376·32	·916	1·356
86	94	43·0	2150·0	1335·73	526·16	1953·79	384·80	·932	1·367
87	93	43·30	2175·0	1359·30	542·30	1971·99	393·37	·949	1·379
88	92	44·0	2200·0	1383·25	558·87	1990·05	402·01	·966	1·390
89	91	44·30	2225·0	1407·62	575·87	2007·96	410·74	·983	1·402
90	90	45·0	2250·01	1432·40	593·31	2025·72	419·54	1·00	1·414

Survey of Line.

It is sometimes convenient to lay out curves (*a*) from a chord such as BC (*Fig.* 2) by offsets at regular intervals as marked m_0, m_1, m_2, m_3....., or (*b*) by offsets from a tangent DH, by offsets x_0, x_1, x_2..... The first method would be used in the case of a re-entering angle where there was difficult ground on the convex side of the curve.

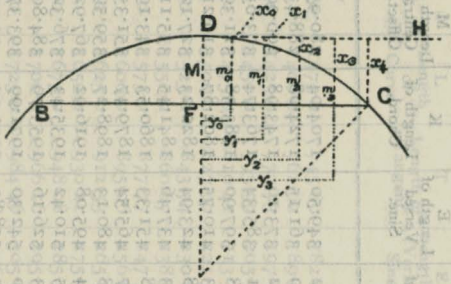


FIG. 2.

In this case we find from the table the value of DF, *i.e.*, M, and can calculate x_0, x_1..... from the formula

$$x_0 = R - \sqrt{R^2 - y_0^2},$$

y_0 being the distance from F to the required position of the offset.

Then $$m_0 = M - x_0.$$

The second method merely requires the calculation of x_0, x_1, etc. This method is applicable in the case where the line has to curve round a hillside or similar difficult ground on the concave side of the curve.

Curves should be designated by degrees, not by the radius.

Our duties in uncivilized countries may necessitate the construction of great lengths of line, although in civilized warfare probably only short lengths would be required. In the latter case the matter is rendered very easy by

the contoured maps which would probably be available. With a map of about $\frac{1}{10560}$, contoured to 50′, it ought to be possible to lay out approximately a line with a fixed ruling gradient and limited curves without preliminary survey or flying levels.

Survey in Civilized Countries with Good Maps.

With contoured maps a few segments of cardboard should be cut representing a few ordinary curves, 2°, 3°, 4°, etc., to the scale of the map. The straight parts of the line may then be drawn on the map, and by means of the cardboard curves these pieces of straight may be connected together in the most advantageous way so as to avoid obstacles, while giving the easiest curves, and by the contours stiff gradients can be avoided. Care should be taken to measure off the proposed line in chain lengths and endeavour to begin and end each curve on a chain peg. This is not only workmanlike, but it saves trouble in grading. The proposed plan of the line can then be submitted for approval of the G.O.C. or other authority. It is advisable, however, before doing so, that the engineers who have to carry out the work should go over all the proposed line, modifying original ideas where necessary.

If approved, the laying out can then go on. Two officers should work, the one doing the theodolite work, the other the levelling. Each day's work should be levelled and plotted before the next begins. Levels should be checked with Ordnance or similar Survey bench-marks wherever such exist, or else by "check levelling" between the ends of each day's work. The variation in levels on checking should not usually exceed ·02′ per 5 miles. The approved plan (or a copy) should always be available for reference in the field, and on it should be marked the distances of curves or straights, *e.g.*, "2° curve 4 chains," "straight 7 chains."

Beginning from any fixed point, the theodolite officer should either interpolate his position from known points or in some other way fix his direction as laid down in plan. His party will consist of four men, one man carry-

ing the instrument, two men chaining, and the fourth with a mallet and bundle of 6″ pegs. The theodolite being set up at the starting point and directed in the required line, the chaining is begun. At each chain a peg is driven into the ground with its top flush with ground level. The forward chain man should always carry a small bandrol with pointed end. The point should be placed on the top of the peg and the latter should be fixed in its proper place by theodolite observation.

On reaching the tangent point of a curve three pegs should be driven in line. The theodolite should be fixed over the centre peg A (*Fig.* 3) and directed in the line of the tangent AX. The angle XAB is then laid out= *half* the angle of the curve. The chain men chain from A to B and fix in a peg; they then go in the direction of C and the angle BAC= XAB is then laid out; similarly for D and any further number according to the number of chains in the curve.

On arrival at the end of the curve the theodolite is moved there, is directed back to the other tangent point, the total angle ADX is laid out= XAD. This gives the new tangent.

FIG. 3.

The observing officer should keep a traverse book and take bearings to known objects so as to correct any small errors in direction or plotting.

If it should happen that he cannot observe all round a curve, he has to work chain by chain, finding the tangent line at each point and starting afresh.

The levelling officer follows, taking the levels on all the chain pegs and on any marked inequalities of ground between. All watercourses must be very carefully noted. Cross levels should be taken where the ground is hilly, *i.e.*, more than $\frac{1}{10}$.

One officer may do both the observing and levelling by laying out about 5 chains and than taking its section. It is better, however, to have two officers.

Cases may occur where it is not possible to begin and end curves on chain pegs, nor to use curves giving tangential angles in even numbers. In such cases the curve formulæ given above should be utilized.

Survey in Uncivilized Countries.

The object of a military railway survey is to obtain a workable line in the shortest space of time. Economy of working speed and length of line are secondary considerations. The limit of radius and ruling gradient will probably be settled by the available power of locomotives (see ante) and the heaviest trains required, with a given velocity, and although it may be possible to work within these limits, a well-laid-out line will have as little of the extremes as possible.

The worst errors of location generally originate in the reconnaissance. The reconnaissance must be of the area or district. Hence it is wise to spend some time in the preparation of a map of the district if such is not available.

Assuming such a map to be prepared, an inspection of it will show approximately the line that should be adopted by noting the watercourses, saddles of mountain ranges, etc. It may be necessary to make a rough section as explained in Section VII.—Roads. In any case a series of *flying levels* should be taken between the points which it is desired to connect. This consists of an approximate section of the approximate line, and from the rough section plotted an idea can be gained of the practicability of the work.

Then the laying out begins. There should be three parties, one to lay out curves and straight, the second to level, the third to make a topographical survey of the ground in the immediate vicinity.

If it is desired to set out a curve changing direction from BA to AC, the curve will usually be set out with chords of 100′ or some submultiple of this length in the case of very sharp curves. If the tangent point comes at an even chainage all the chords will be equal and of the fixed length except the last, for which an odd length of

chord will be required to close on to the tangent point. The corresponding angle for any chord can be found by calculation from the curve tables below. If the curve commences at an odd chainage the first chord will also be of odd length, in order to carry through the chainage of the main line. Thus if it is found necessary to change direction from BA to AC the angle OAC is observed. From this, and the radius decided on the tangent lengths AB and AC are calculated, and the chainage of point B fixed. Suppose it to be 7 ch. 59′. Then the first chainage point on the curve will be that for 8 ch., the first chord being (100 − 59 =) 41′. The other chords will all be 100′ each, except the last which can be found by calculating the total length of the curve and finding the distance of the tangent point C from the 10th chain peg.

FIG. 4.

It is important to remember in setting out a curve that the theodolite is deflected towards the inside of the curve by an angle equal to ½ the angle subtended at the centre by the particular chord which is being measured off at the moment.

The chaining should be horizontal and the chain stretched to its full extent.

Each day's work should be plotted and the gradients fixed before going on to the next, so that any errors can be rectified.

After the work has been plotted and graded the line should be gone over and the depth of cutting or height of bank at each chain peg written legibly on a smooth peg and inserted at the proper place.

The formation width in cuttings should be marked out. The side slopes can be made after traffic is opened on the line unless the cutting be very deep (which ought to be very exceptional on a military line).

The bottoms of banks must then be laid out. The slopes should not be steeper than 1½ to 1. It is desirable that profiles (as in redoubt parapets) should be erected here and there.

The earth for banks should, if possible, be obtained from cuttings and tipped. If borrow pits have to be used, the cutting edge of a borrow pit a feet deep should be distant from the toe of the bank at least $\frac{3a}{2}$ when the slope is 3 to 2.

After the line has been finished to formation the first layer of ballast is put on and centre pegs are very carefully placed and marked at ½-chain intervals.

It is well to postpone ballasting till the banks have settled.

Bridges.

Bridge sites should always be selected first, and the line should be made to fit in. It is of great importance to have short bridges, good foundations, and solid ground for abutments.

When operating with the sea as a base it will generally be possible to obtain a number of girder beams of various lengths to suit the maximum rolling loads which may be expected. Every consignment of railway plant should include a supply of pipes of 2′ to 3′ diameter, made up by bending and rivetting up corrugated-iron sheets, for use as small culverts. These will carry any loads if laid with 3′ 6″ of earth cushion above them. There should also be a few 10′, 20′, and 40′ girders if the line is made in a country where timber is scarce. The piers can be built temporarily of sandbags and the girders laid above. The line can then be opened while arrangements are being made for the more permanent construction of the piers in stone, brick, or concrete.

Where time and material for the erection of arches are available, they are preferable to girders.

The waterway to be allowed in any bridge must be largely settled by the judgment of the engineer. In military lines for temporary use it will often be economical to take the risk of a temporary stoppage of traffic due to a flood. In the case of "Irish bridges," it should be remembered that a depth of water exceeding 18″ over the rails will generally stop traffic by putting out the fire and

damaging the boiler in 4′ 8½″ gauge locomotives. In narrower gauge engines the permissible depth is about half this.

If timber is plentiful, girders may be entirely dispensed with, and all the bridging done of wood. It has the disadvantage of being more easily destroyed. A few samples of timber bridges are given in *Figs.* 5 to 7. These trestles should be 10′—12′ apart if the roadbearers are not strutted, but if these are supported by braces from beneath they can be 20′—25′ apart. Solid crib piers may also be made by successive tiers of sleepers at right angles to each other, notched at the ends, or spiked, and on these the road bearers are laid. The inside of the crib may be filled with stones.

The constructive details of railway bridges cannot be entered fully into here.

In calculations for roadbearers, whether of timber or steel, for railway bridges the allowance for impact may be taken as follows :—

Span, ft.	Allowance for Impact. Add % of Calculated Load.
5	30
10	25
20	20
30—90	15
100	10

The equivalent uniformly distributed bending loads for the heaviest British locomotives on a single track are as follows :—

Span in Feet.	10	15	20	25	30	35	40
Tons per foot-run	3·99	3·72	3·44	3·35	3·28	3·06	2·88

Span in Feet.	45	50	55	60	70	80	100 & Over.
Tons per foot-run	2·67	2·50	2·27	2·27	2·27	2·26	2·24

On the Belgian railways these figures must be increased by 30 per cent. in spans of below 20′ and by 15 per cent. for the remainder. Where rails are used as girders to span small openings up to about 10′, the following "platelayer's rule" will be found to give safe results :—"For each foot of span use one rail as a girder under each of the two running rails." Thus a 5′ span requires 5 rails laid side by side under each running rail and so on.

Crib piers for the top 8′ should be 1 sleeper long (transversely to the track).

Crib piers from 8′ to 18′ from the top should be 2 sleepers long (transversely to the track).

Crib piers over 18′ from the top should be 3 sleepers long (transversely to the track).

Above 20′ sleeper cribs are not economical as compared with trestles. Brace all piers with rails horizontally at vertical intervals of 6′ or so.

Earthwork piers with sandbag revetment should be 12″ × 6″ in plan for 40′ span, 12′ × 4′ 6″ for 10′ span, both with sides battered 6/1. A timber frame is required on top to distribute the load.

Fig. 5 (p. 15 of Tyrell's book) shows a general type of timber trestle. The tiers should not exceed the heights shown. Where more than one tier is required variations in height to suit the section of the opening should be made in the bottom tier only, all the other tiers being uniform throughout the bridge.

Fig. 6 (p. 17 of Tyrell's book) shows the details of one tier of a typical trestle. All trestles must have longitudinal bracing both diagonal and horizontal at the top of each tier. The latter also forms a convenient working platform for erection of the next tier.

Joints.—All bolts $\frac{3}{4}$″ diameter, with washer at head and nut.

$\frac{3}{4}$″ to $1\frac{1}{4}$″ bolts take 3″ to $4\frac{1}{2}$″ diameter washers $\frac{3}{4}$″ thick.

Drift bolts are $\frac{3}{4}$″ square or round iron.

Smooth rods are better than jagged in timber.

Round have 25 per cent. more holding power than square.

1″ round bolt in $\frac{3}{4}$″ hole in Norway pine has 9,000lbs. pull per F.R.

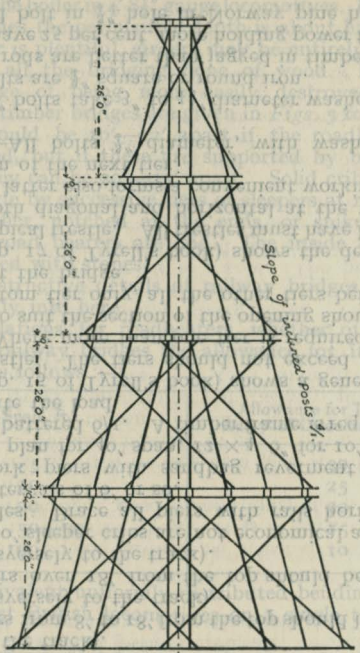


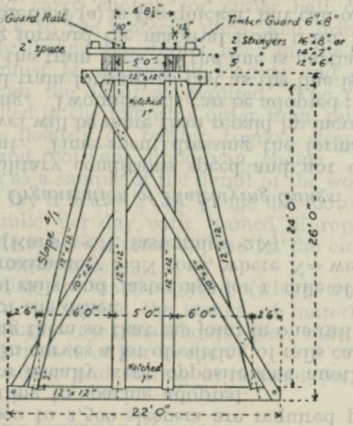
FIG. 5.

All bolt holes $\frac{1}{8}$" smaller than bolt.

Screw bolts 50 per cent. more hold than smooth.

Spikes.—Straight, with chisel point are best (*M.P.B.*, p. 202).

Holding pull = 300lbs. per square inch of surface of spike in fir. Holes half diameter of spike.



1st Tier and General Details

FIG. 6.

Dogs.—¾" iron. Their points should be sharpened by bevelling on the inside only, so as to draw together the parts that are being joined.

Platelaying.

Ballast.—Objects—(1). To distribute pressure over a larger area than that of the sleepers. (2). To keep the sleepers dry. (3). To afford facilities for packing sleepers when they have sunk.

Ballast may be laid in two parallel heaps, so as to be just under the centre of the rails. Two cubic yards of ballast are used for each yard of standard gauge track in first-class work, but half or three-quarters of this amount is quite enough where very high speeds are not required. Points and crossings, however, should be as fully ballasted

as possible. Cross-draining of the line should be carefully attended to. There should be a depression in the ballast at every 30′, on alternate sides at centre of rail. A stock of spare ballast should be kept.

Cross *sleepers* are usually 9′×10″×5″. Round logs 9′×10″ or 12″ diameter sawn longitudinally may be used; the flat side must be downwards. If fishplates are not used, a larger sleeper should be placed under the chairs at the joints, but fishplates can only be omitted at speeds of about 3 miles an hour or under. Cross sleepers should not be packed with ballast in the middle, a space should be left 1½′ to 2′ wide, which does not rest on ballast or the ground, so that the support may be received from nearly under the rails. With flat-bottomed rails, sleepers should always be bored to a template before being laid out along the line. One carpenter and one labourer can bore and also adze rail seats to a cant of $\frac{1}{20}$, which is required if bearing plates are not used, at a rate of 60 sleepers a day.

From 1,900 to 2,500 sleepers are required per mile of track according to spacing adopted.

Joints are usually kept opposite one another on the straight. On curves a lot of cutting of rails can be saved by staggering them so that the joint in one rail is opposite the centre of the other.

Weight of rails and fastenings for 1 mile of flat-footed track= approximately 1·8N tons, where N= weight in lbs. per yard. (Rails 1·6N, fastenings ·2N).

Organization of Platelaying Gangs.

Under military conditions speed and not economy is all-important. Time spent dressing the formation accurately to level will be more than repaid by increased speed of platelaying. Two methods can be adopted: (*a*) pushing the material train forward as fast as the line is linked up, (*b*) keeping the train back till the line is partially packed, and sending forward the material from train to railhead by lorry. Method (*a*) is the quicker, but can only be used if the formation is fairly level. In either case the material

train should carry enough for either half or one day, running back to the material depôt and bringing out a fresh supply during the dinner hour in the latter case. No delay must be allowed in loading and despatching material from the depôt as required. The train should be marshalled in the following order from railhead backwards, rails (loaded on bolster trucks), sleepers, fastenings, food and tool vans, brake van, engine. The following is given as a sample of the detail of the working party required to lay a heavy 4′ 8½″ gauge flat-footed road at a rate of 1 mile per day with trained European labour. The exact distribution must depend on the circumstances of any particular case :—

(A). Loading in material yard (where trucks can be brought close alongside the stacks of material) :—Rails and fastenings.—150 man-hours per mile of track. Sleepers.—¼ man-hour per sleeper.

(B). Unloading and linking at railhead (in order from front to rear).

1.	Trimming formation, if necessary ..	6 men.
2.	Distributing sleepers	30 ,,
3.	Aligning and spacing sleepers	4 ,,
4.	Bolting up fishbolts	6 ,,
5.	Gauging	6 ,,
6.	¼ spiking	6 ,,
7.	Distributing fishplates, etc.	4 ,,
8.	Loading and pushing rail lorry and distributing rails	18 ,,
9.	Unloading rails and sleepers from train ..	8 ,,
10.	Full spiking (may be behind train) ..	12 ,,
11.	Rough packing (may be behind train) ..	24 ,,
12.	Picking up scattered fastenings and tools	4 ,,
		129

N.C.O.'s are not included in the above.

If more than one trolly is used, which is advisable where the lead from train to railhead is more than two or three rail lengths, gang No. 8 must be increased accordingly. Horses can be used for pulling the lorry if available.

Track-laying machines are largely used in America, and should be utilized if they are available or can be made, as they economize labour considerably.

The following rule for the amount of expansion at joints is simple and found satisfactory in India for rails of 36′ length :—" If the rail feels cold to the touch, allow $\frac{3}{8}$″. If it feels warm allow $\frac{1}{4}$″. If it is too hot to touch allow $\frac{1}{8}$″." For temperate climates these allowances may be halved.

When the whole road is in good running order, the care may be left to a maintenance gang of three platelayers per mile (average) of track.

Points and Crossings.

The following formulæ are given for calculating the dimensions most often required. These can however be obtained near enough for practical purposes by drawing out what is required on a scale not smaller than 20′ to 1″, and this method is recommended in the more complicated cases.

Definitions (*Fig.* 13).

G= *Gauge.*

Nose of the crossing.—The point of intersection of the inside edges of the crossing rails. This is an imaginary point to which *lead measurements* are referred, and is some 3 or 4″ in front of the actual blunt nose.

R= *Radius of crossing.*—The radius of the curve on which the diverging track crosses the straight one.

d= *Clearance.*—The distance from inside edge of stock rail to inside edge of switch rail measured at the heel.

I= *Inclination number* or *number of crossing.*—The cotangent of the angle of crossing, measured by the distance from nose of crossing along the inner edge of one intersecting rail, of the point, at which the perpendicular distance from the inner edge of the other intersecting rail is unity.

L′= *Curve lead.*—The distance from springing of curve to nose of crossing measured along the straight.

l' = *Switch lead.*—The distance from springing of curve to heel of switch measured along the straight.

L = *Lead of crossing.*—The distance from the heel of switch to nose of crossing measured along the straight $= (L' - l')$.

From the following formulæ it will be easy to calculate, for a given gauge, the lead and radius of crossing, etc., required for a given number of crossing, or *vice versâ*, to calculate the crossing required to fit a given curve.

In the case of a turn-out from the straight

(*a*). $R = 2GI^2$ (approximately)
$= 2GI^2 + 1\frac{1}{2}G$ (very closely).

(*b*). $L' = 2GI$ (approximately).

(*c*). $l' = 2I\sqrt{Gd}$ (approximately).

(*d*). $L = L' - l'$.

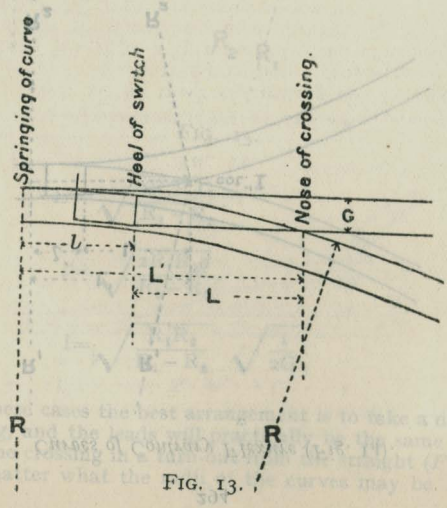


FIG. 13.

Curves of Contrary Flexure (*Fig.* 14).

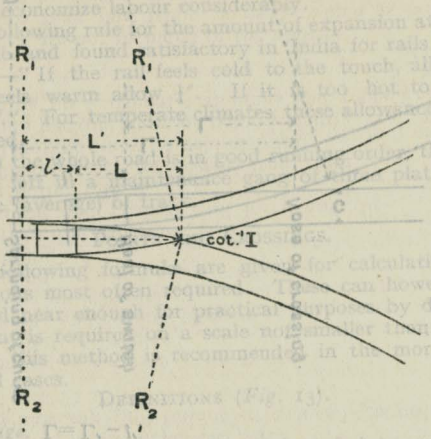


FIG. 14.

If R_1 and R_2 are the radii of the curves

(*e*). $$L' = \sqrt{\frac{2R_1R_2G}{R_1+R_2}} \text{ approximately.}$$

(*f*). $$l' = \sqrt{\frac{2R_1R_2d}{R_1+R_2}} \text{ approximately.}$$

(*g*). $$I = \sqrt{\frac{R_1R_2}{R_1+R_2}} \sqrt{\frac{1}{2G}}.$$

(In the special case of the radii being equal $R = 4GI^2$).

Curves of Similar Flexure (Fig. 15).

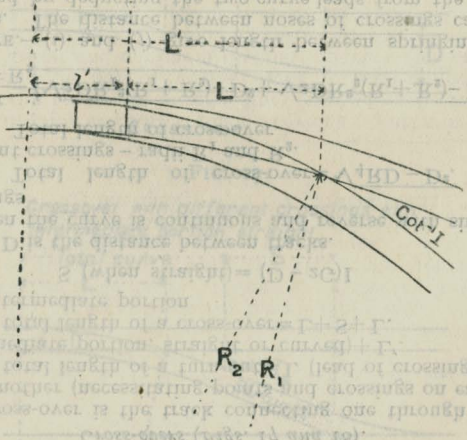


FIG. 15.

$$(e'). \qquad L' = \sqrt{\frac{2R_1R_2G}{R_1 - R_2}}.$$

$$(f'). \qquad l' = \sqrt{\frac{2R_1R_2d}{R_1 - R_2}}.$$

$$(g'). \qquad I = \sqrt{\frac{R_1R_2}{R_1 - R_2}} \sqrt{\frac{1}{2G}}.$$

In these cases the best arrangement is to take a definite crossing, and the leads will practically be the same as for the same crossing in a turn-out from the straight (*Fig.* 16) —no matter what the radii of the curves may be.

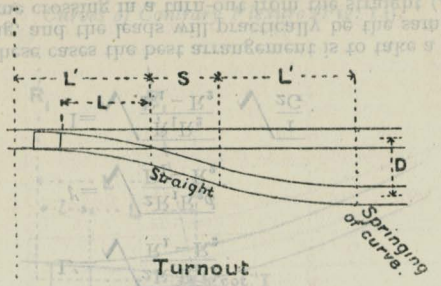


FIG. 16.

Cross-overs (*Figs.* 17 *and* 18).

A cross-over is the track connecting one through line with another (necessitating points and crossings on each).

The total length of a turn-out = L (lead of crossing) + S (intermediate portion, straight or curved) + L'.

The total length of a cross-over = L + S + L.

The intermediate portion

(*h*). S (when straight) = (D − 2G)I

where D is the distance between tracks.

When the curve is continuous and reverse with similar crossings

(*i*). Total length of cross-over = $\sqrt{4RD - D^2}$. With different crossings – radii R_1 and R_2.

(*j*). Total length of cross-over

$$= \frac{1}{R_1 + R_2}\{\sqrt{2DR_1^2(R_1 + R_2) - D^2} + \sqrt{2DR^2{}_2(R_1 + R_2) - D^2}\}$$

NOTE.—(*i*) and (*j*) give length between springings of curves. The distance between noses of crossings can be deduced by deducting the two curve leads from the total length.

The case of different crossings with a straight intermediate portion is more complicated.

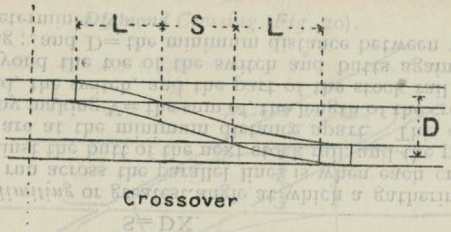


FIG. 17.

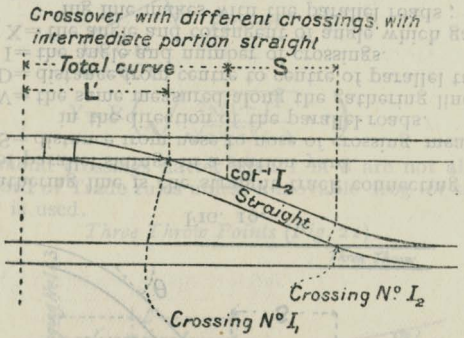


FIG. 18.

If I_1, I_2 be the crossings (of which I_1 is the more acute), R_1R_2 the radii of the corresponding curves;

Then the distance from springing of larger curve to the end of curve measured along the straight track

$$= \frac{2GI_1^2}{\sqrt{I_2^2+1}} \left(\sqrt{I_2^2+1} - I_2\right) \quad \ldots\ldots(k),$$

and the distance, measured along the straight, from this point to the nose of the opposite crossing

$$(l). \qquad = I_2 \left(D - \frac{G}{2}\right) - \frac{2GI_1^2I_2}{\sqrt{I_2^2+1}} \left\{\sqrt{I_2^2+1} - I_2\right\}.$$

Gathering Lines (*Fig.* 19).

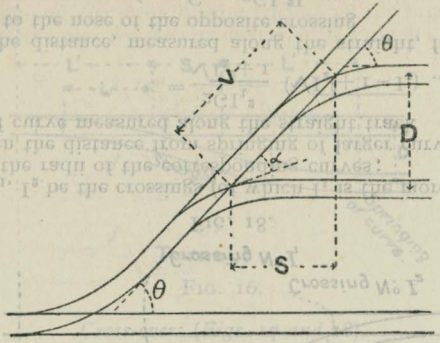


FIG. 19.

A gathering line is the straight track connecting up a series of parallel sidings in a station yard.

Let S= distance from nose to nose of crossing measured in the direction of the parallel roads.

V= the same measured along the gathering line.

D= distance from centre to centre of parallel tracks.

a, I= the angle and number of crossings.

θ, X= the angle and cotangent of angle which gathering line makes with the parallel roads ;

then $V = D\sqrt{1 + X^2}$

$S = DX$.

The *limiting* or greatest angle at which a gathering line can be run across the parallel lines is when each crossing fits against the butt of the next stock rail, and the parallel tracks are at the minimum distance apart. This can be found by making V= the sum of, the length of the crossing, the lead, the switch, and the part of the stock rail which lies beyond the toe of the switch and butts against the crossing ; and D= the minimum distance between tracks. This determines X.

Diamond Crossing (*Fig.* 20).

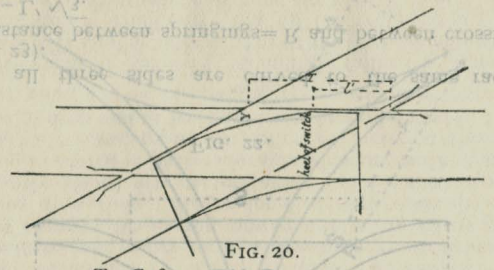


FIG. 20.

$T = GI^2$

$R = 2GI^2$

$$Y = R\left(\sqrt{\frac{2\sqrt{1+I^2}}{\sqrt{1+I^2}+A}} - 1\right).$$

Diamond crossings flatter than 1 in 8 are not allowed by Board of Trade rules unless a movable frog or similar device is used.

Three Throw Points (*Fig.* 21).

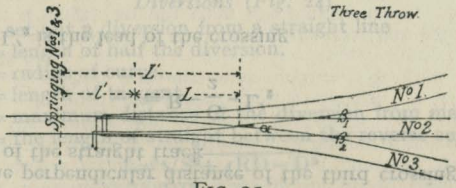


FIG. 21.

$$L' = \sqrt{\frac{2R_1R_2G}{R_1+R_2}}, \text{ or if } R = R_1 = R_2 \quad \sqrt{RG}$$

$$l' = \sqrt{\frac{4R_1R_2d}{R_1+R_2}} \quad ,, \quad ,, \quad \sqrt{2Rd}$$

$$L = L' - l'$$

$$I = \sqrt{\frac{R_1R_2}{R_1+R_2}} \times \sqrt{\frac{1}{2G}} \quad ,, \quad \sqrt{\frac{R}{2}} \times \sqrt{\frac{1}{2G}}$$

Triangles (*Fig.* 22).

These are used as temporary alternatives for turntables. In the first case with one side straight :—

If R is the radius of the curves, the distance between springings of the two curves on the straight is $2R - G$ and distance between the two crossings on the straight $S = 2R - G - 2L'$ where L' is the curve lead of the crossings, and the perpendicular distance of the third crossing from centre of the straight track

$$= R - \frac{G}{2} - L'_2$$

where L'_2 is the lead of the crossing.

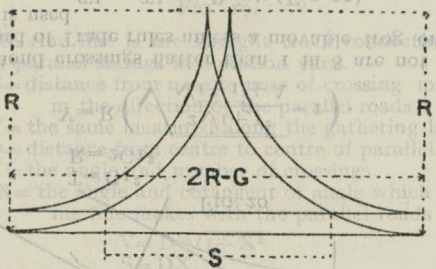


FIG. 22.

If all three sides are curved to the same radius (*Fig.* 23).

Distance between springings = R and between crossings $= R - L' \sqrt{3}$.

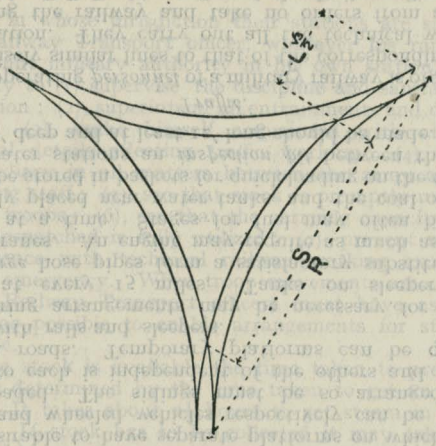


FIG. 23.

Diversions (*Fig.* 24).

To set out a diversion from a straight line

L = length of half the diversion.

R = radius of curve.

T = length of tangent.

D = maximum distance of the diversion from main line.

S = the length of straight between the reverse curves.

Then $L = \sqrt{S^2 + 4RD - D^2}$

$$T = \frac{RD}{L+S}.$$

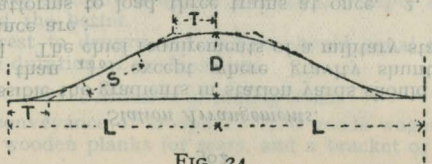


FIG. 24.

Station Arrangements.

If possible the gradients in station yards should not be steeper than $\frac{1}{100}$, except where gravity shunting is required. The chief requirements of a military station of importance are :—

1. Platforms to load three trains at once. 2. Sidings for stabling at least one spare train. Further separate siding accommodation for marshalling troop trains must be arranged either at the entraining point or within a short run of it. 3. Level ground near but entirely separated from the station for forming up troops. 4. Cover for stores. 5. Sheds for refreshment of troops. 6. Hospital near. 7. Water for men and engines. 8. Fuel stored. 9. Latrines.

Platforms should be 2′ 6″ high, not less than 12′ broad, and of a length greater than the longest train. As each carriage or truck averages 20′, a train of 30 carriages requires a platform of at least 200 yards. At large stations it is desirable to have separate platforms on which men, horses and wheeled vehicles respectively can be loaded or unloaded. The sidings must be so arranged that access to each is independent of the others and of the through roads. Temporary platforms can be quickly made with rails and sleepers.

Watering arrangements may be necessary for heavy traffic at every 15 miles. Tanks on sleeper cribs with *large* hose pipes form a satisfactory substitute for water cranes. An engine may require as much as 2,000 gallons at a time. Stages for fuel may often be conveniently placed near water tanks, and the coal or coke should be stored in baskets for quick loading on the tender.

At water stations an *inspection pit* between the rails about 3′ deep and at least 12′ long should be made.

Traffic.

The operating *personnel* of a military railway is organized on precisely similar lines to that of the corresponding civil organization. They carry out all the technical work of operating the railway and take no orders from anyone except the D.R.T., his staff, and the Railway Transport

officers in whose jurisdiction their stations are situated. The Railway Transport officer, whatever his rank, has paramount military authority in his own station. It is his duty to (1) supervise the discipline and sanitation in his station ; (2), superintend all entrainments and detrainments ; (3), make himself acquainted with all local technical details affecting traffic working ; (4), act as intermediary in all matters between the army and the operating staff ; (5), see that stock is promptly unloaded by the troops ; (6), see that the carrying capacity of all stock despatched is fully utilized ; (7), prevent military interference with technical railway working except on serious emergency. When troop movements are contemplated Railway Transport officers must have as much notice as possible to enable arrangements for stock to be made.

If the stock is available the time taken to prepare a train is determined by the time taken to get an engine ready. It takes about 2½ hours to get steam in a cold engine. If stock has to be collected it may take from 24 to 48 hours.

It takes half-an-hour to entrain a battalion of infantry, which requires two trains of 25 vehicles each ; one hour for a squadron of cavalry, which requires one train of 35 vehicles ; 1½ hours for a battery of artillery, which requires two trains of 29 vehicles each.

Infantry take 20 minutes to load a train.

Cavalry and artillery take 40 minutes.

Railway wagons should not be used as temporary magazines.

The least interval between trains on the same line (double) is about 10 minutes. Provided sufficient reliefs of running staff are available the quicker empty stock is returned the better.

The rest to drivers and stokers should equal at least half the duration of working time.

Utilization of Rolling Stock.

For conveyance of troops, covered goods wagons only require wooden planks for seats, and a bracket or two at

the ends for lamps. For horses and other animals, a portable ramp is necessary, hinged at the bottom. The side doors may be made to open in three parts, the lower flap to form a ramp, while the two upper portions form a lead. Ventilation must be attended to. Horses are best placed parallel to the rails, with their heads towards one another, a breast bar being provided across the wagons, with rings to fasten the horses' heads. The space between the rows of horses is utilized for saddlery, attendants, etc. Chains, tightened at one end by a screw shackle, may be substituted for breast-bars. These require to be well covered with leader and straw so as not to chafe the horses' breasts. Horses thus take up more room, however, than if placed at right angles to the track.

The principles of *ambulance trains* are briefly as follows:—(1). Use the longest carriages possible. (2). Give a free passage 3′ wide from end to end of the train, for medical officers and attendants. This can be done by sliding doors at the ends of the carriages. (3). Have doors, which must be wide enough for stretchers, at the sides also for entraining of patients. (4). Provide each carriage with a tank for water. (5). Have means of warming the carriages in cold weather. (6). Have good accommodation for medical officers with every train, and let their carriages be connected by signals with all parts. (7). Provide cooking wagon with each train. It should be marshalled about the centre. (8). The sick wagons should be arranged so that the sick may be brought in, conveyed, and taken out at the end of the journey on the same stretcher. The stretchers should be arranged so as to be affected as little as possible by the shaking of the train, so they should either be slung from the roof by ropes, or from the sides with leather straps, or rest on springs. Cushioned railway carriages can be used for the less badly wounded.

Defence of a Line of Railroad.

The work of the engineers in defence of a line of rail will be somewhat as follows:—(1). Erect strong barrier gates at each end of a station, bridge or viaduct. (2). Erect block-houses for protection of small bridges, cuttings,

curves and cross-roads. (3). Clear ground round every station or post. (4). Erect bridgeheads at each end of long bridges and viaducts, enclosing approach embankments where such exist. Arrange for musketry fire to bear on bases of piers, to prevent their being mined. (5). Provide loopholed barrier gates at tunnels.

It is recommended that in cuttings the blockhouses should be erected across the line, the trains passing under them.

Each blockhouse should have provisions, water, fuel, ammunition, and signalling implements.

For destruction of railway, see Section V.

RAILWAY TRAFFIC ORGANIZATION.

Traffic Department.—Organized under a superintendent of line at headquarters of the railway. For traffic purposes the system is divided into districts, each comprising 100 to 150 miles of line, under District Superintendent. A district is divided among traffic inspectors, each responsible for working over 30—40 miles of line. Stationmasters at large stations rank as inspectors and are responsible direct to the District Superintendent. The station staff, including signalmen, porters, guards, and brakemen of trains while in the station, are under the orders of the stationmasters or foreman porters acting under them. Platelayers when temporarily employed as fog signalmen pass under the traffic department. In general the traffic department deals with all movements on main line and in stations and sidings and arrangements connected therewith. The goods department is a branch of traffic department dealing only with loading and unloading of wagons and clerical work, such as invoicing, etc. The goods department staff is generally separate, but in small stations the work is done by the traffic officials.

Loco. Department.—Organized under a Chief Loco. Superintendent, with superintendents under him for Running and Works Branches. The railway is divided into loco. districts similar to, but not necessarily coincident

with, the traffic districts. Loco. sheds are established at chief stations, to which engines, drivers and firemen are posted. These will not usually work beyond the limit of their districts. A roster, termed the "engine link," is got out for each shed, arranged so that the engine and men return to shed each night, if possible working a return train to avoid unbalanced mileage and light running. Drivers when on the road or in stations are under the guard of the train (traffic department). Fitters to do small repairs are posted to each shed; for large repairs engines must go to the general works or nearest repairing depôt. Locomotive power for special trains not on the time table is requisitioned from the shed foreman by traffic inspectors or stationmasters. Three hours' notice should be given before the engine is required. Full particulars must be sent to the district office at once.

The rolling stock and stores departments, though separately organized, are practically branches of loco. department (works branch).

Engineering Department.—Organized under chief engineer with branches for construction and maintenance.

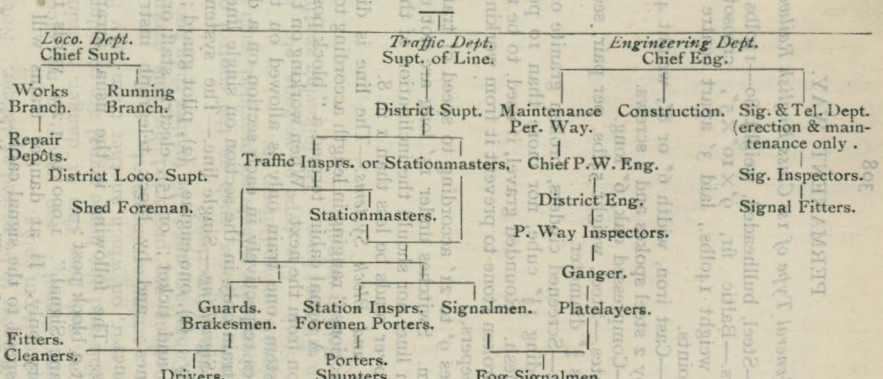
Maintenance of line is organized under permanent way engineer, with district engineers each in charge of about 120 miles of line.

A permanent way district is divided among inspectors in charge of 30—40 miles each. The minor repairs are done by platelaying gangs, consisting of ganger and 3 men.

On double line 1 gang to $1\frac{1}{4}$ miles of line.
On single ,, ,, ,, 2 ,, ,,

One large "relaying" gang of about 50 men to each district. In case of an accident it is the duty of the Loco. Department to find a breakdown gang to clear the line. But the engineering department must arrange to make the track safe for passage of trains when the line has been cleared.

Railway Organization.



PERMANENT WAY.

General Type of 1st Class English Railway.

Rails.—Steel, bullheaded, weight 80—110lbs. per yard.

Sleepers.—Baltic fir, 9′ × 10″ × 5″, creosoted under pressure, weight 140lbs., laid 3′ apart centre to centre, 2′ 2″ at joints.

Chairs.—Cast iron, width 6″ or 8″, weight 45lbs. each, secured by 2 steel spokes and 2 screws.

Keys.—Compressed oak, 6″ long.

Fishplates.—Steel, weight 54lbs. per pair, secured by 4 steel bolts ¾″ diameter.

Ballast.—Screened cinders, broken granite or slag, size not exceeding 1½″ cube, nor more than 10 per cent. to pass ½″ mesh. Rounded gravel, if used, to be mixed with sand or broken stone to prevent it from working out from under sleepers.

Switches 9′ to 21′ according to speed of traffic passing over them. Switches under 15′ long are not usually put into main line, nor should the inclination of the crossings for cross-over roads be less than 1 in 8.

Signals and Block Systems.—The line is divided into "block sections," ranging in length according to frequency of traffic. A signal cabin, termed a "block post," divides one section from the next. When working on the absolute block system, one train only is allowed on the up and down lines respectively in each section on a double line, and one train only in the section on single lines.

Block Signalling.—Single line.—The system may be worked by: (1), one engine; (2), pilot guard; (3), staff; (4), staff and ticket; or (5), electric staff or tablet, on single lines; and by block telegraph instruments on double lines.

Signals.—The following is the usual arrangement of signals at a block post:—

"Distant Signal." 1,000 to 1,200 yards from cabin. Cautionary only. If at danger trains will proceed at reduced speed to the signal cabin.

"Home Signal." The true dividing post between sec-

tions ; and never to be passed at danger. Not to be more than 80 yards from cabin.

"Starting Signal." 100 yards in advance of cabin. Trains may not pass this at danger. Trains standing between this and the home signal are considered clear of section in rear, on which another train may be accepted under the warning arrangement.

All junctions are protected by this arrangement of signals. Cabins are not to be further than 200 yards from facing points of junctions.

For minor purposes, such as the control of trains in station, subordinate signals are provided, such as platform starting signals, ground discs, etc.

Rolling Stock.—The type of wagons, etc., used differs slightly on different lines. The following are the capacities of typical British vehicles :—

Capacity of British Rolling Stock.

Description of Stock.	Dimensions (inside).	Cubic Capacity.		Load.	Average cubic feet per ton.
		Actual.	If loaded to a height of 5'.		
		Feet.	Feet.	Tons.	
Open goods wagon, L.N.W.R. ..	15' 6" × 7' 2" × 3' high ..	333	555	10	55
,, ,, ,, L.S.W.R...	14' 11½" × 7' 6½" × 2' 11⅜" high.	337	562	10	56
Covered goods wagon, L.N.W.R.	17' 9½" × 7' 1" × 6' 11½" high at centre.	807	621	10	62

Truck Space taken up by Army Vehicles.—*Guns.*

	Weight.		Width over all.	Length without Limber.	Limber.	Length required in Truck.
	Gun and Carriage.	Limber.				
	tons. cwts.	cwts.	ft. in.	ft. in.	ft. in.	ft. in.
13-pr. Q.F.	19½	13	6 3	12 2	5 3	13 0
18-pr. Q.F.	1 5	15	6 3	13 8	5 4½	14 0
5-in. B.L. Howitzer	1 3¾	22½	6 2	9 3	5 6	15 1
60-pr. B.L.	4 11	16½	6 6½	21 7	7 7	32 4
Maxim Gun I.F. Carriage III.	9¾	..	..	10 3	..	10 3

TRUCK SPACE TAKEN UP BY ARMY VEHICLES.—*Ammunition Wagons.*

	Weight. Without Limber.	Weight. Limber.	Width over all.	Length without Limber.	Limber.	Length required in Truck.
	tons cwts.	cwts.	ft. in.	ft. in.	ft. in.	ft. in.
13-pr. Q.F.	15¾	14¾	6 3	7 11	6 1	14 0
18-pr. Q.F.	18¾	17¾	6 3	8 0	6 0	14 0
5-in. B.L., Mark II. ..	1 9¼	19½	6 2	8 4	6 9	15 1
60-pr. B.L. (converted Q.F. 15-pr. wagons)	1 9¾	18¼	6 0	8 3½	5 11	14 2½

TRUCK SPACE TAKEN UP BY ARMY VEHICLES.—*Wagons and Carts.*

Nature of Vehicle.	Length taken up in truck, shaft or pole detached.	Additional length for second similar vehicle.	Width over all.
	ft. in.	ft. in.	ft. in.
Wagon, G.S., Mark IX. to X.*	13 7	13 3	6 4
Wagon, ambulance, Mark VI.	13 10	13 10	7 0½
Wagon, pontoon, R.E., Marks IV.* and V. ..	17 4	16 4	6 8
Length of pontoon on wagon	21 0	21 0	6 8
Wagon, cable, telegraph and limber, R.E. ..	16 1	16 1	6 2½
Wagon, limbered, G.S., Mark I.	13 9	13 3	6 4
Cart, forage (shafts on)	13 10½	0 3	6 1
Cart, Maltese (shafts on), Mark V. and V.* ..	12 6½	0 0	6 1
Cart, water tank (ditto), Mark II.*	13 11	1 1	6 1
Cart, tool, R.E. (ditto), Mark II.	10 9	6 0	6 2½

Passenger vehicles are now nearly always bogies of lengths up to 60′, with 5 to 8 compartments each. A compartment holds 8 men with their kits, sitting, or 5 men if 3 are to sleep at a time.

Horse boxes, 18′ long, hold 6 horses each.

The approximate bulk of military stores is as follows :—

Hay (compressed)	116	cubic feet per ton.
Biscuits	112	,, ,,
Bran (compressed)	42	,, ,,
Flour	80	,, ,,
Oats	80	,, ,,
Sugar	60	,, ,,
Preserved meat	67 to 75	,, ,,

Fodder, not compressed, may be taken at about 170 to 180 cubic feet per ton.

Ordnance stores may be taken at 60 cubic feet per ton and with them full loads are generally obtainable.

Narrow Gauge Railways.

Light or temporary military lines are usually of 2′ 6″ gauge, with flat-footed rails, 36 or 56lbs. per yard, spiked to sleepers, 3′ or 2′ 6″ apart, sleepers 5′ × 9″ × 4½″. Rails should rest on bearing plates to give them a cant inwards of 1 in 20. The following is the detail of an active line in working order, and will serve as a guide :—

Length, 27 miles (single).

Stations, 13, including 2 termini and junction.

Ruling curve, 10 chains ; grade 1 in 65.

No. of locomotives, 7.

Speed of trains, 20—25 miles per hour.

No. of trains daily each way, 10 (average).

Signalling arrangements : staff and ticket. One semaphore signal (working from platform) 80 yards on each side of station.

No. of employés.

(1). Traffic dept.		65
(2). Loco. dept. (*a*). Running		15
(*b*). Workshops		10
(3). Permanent way maintenance		30

Power of Narrow Gauge Locomotives.

(Average, and in good running order).

Tractive force with 100 lbs. mean pressure.	Cylinder.	Weight of Loco. in running order.		Speed per hour.	Will haul			
		4 whl. Cpl.	6 whl. or bogie.		On level	1 in 100	1 in 40	1 in 25
lbs.	in.	ton cwt.	ton cwt.	miles.	tons	tons	tons	tons
5000	10	13 0	14 15	15 to 20	340	110	53	34
6000	11	15 0	16 15	15 to 20	420	130	65	40
7200	12	16 15	19 0	18 to 25	500	160	80	50
8450	13	18 0	20 10	18 to 25	575	190	95	60
9330	14	20 0	23 0	20 to 30	650	210	105	67

N.B.—When starting on the incline, loco. will take (in fine weather) ·66 of load named.

Permanent Way Removal.

Railway demolition, as such, is treated of in Section V. It may occasionally be desirable to remove the rails, sleepers, etc., of an existing railway, for the purpose of relaying elsewhere. The chairs would not be removed from the sleepers, and the material should be at once ready to be laid again. The work has usually to be done from one point only, towards which empty trains must be backed from the nearest cross-over road or siding.

Capacity of ordinary goods wagon is 40 sleepers (chaired) or 6 tons of rails.

Speed of trains, whether backing empty, or going away loaded, should not exceed 15 miles per hour between the nearest turn out and the railhead. Any mishap here would delay the work very greatly.

Most convenient length of train is 12 wagons, and one brake van next the engine to carry tools, etc. This train

will hold about 250 yards of single line, *i.e.*, 3 times its own length.

Should a cross-over road on a double line, or a turn-out on a single line, not exist within 5 miles of the railhead, one should be temporarily laid, using contractors' points and crossings. A gang of 50 men can lay 100 yards of temporary siding and connections in 1 hour. This will accommodate a train of above size.

The system of removal differs on single and double line.

Double Line.—Removing one Line only.—The material is loaded direct into the wagons standing opposite the place in the road from which taken. The line should be prepared by 2 men in advance with sledge hammers, knocking off 2 out of 4 fish bolts, and removing all keys except 3 per rail, one at each side of joints, and one at the centre. They can prepare 200 yards per hour without stopping traffic, which can pass safely at low speeds over the line in this state.

Party for loading up each wagon (1 rail length= 10 yards) :—

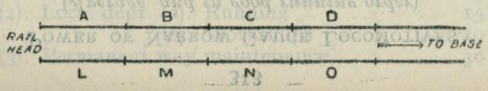
In the wagon, packing material	2 men.	
Loading into wagon	12 ,,	
Removing remainder bolts and keys and collecting fish-plates, etc.	4 ,,	2 sledge hammers.
Unbedding rails and sleepers		2 crowbars.
		2 picks.

To load a rail requires 12 men ; a chaired sleeper, 6 men.

Total party for one train of 12 wagons= 12 × 16= 192 men.

Removal proceeds at rate of one train length in 10 minutes, or half-hour for 250 yards. While the train is away, the road can be prepared, sleepers unbedded, etc., in advance.

Removal of both Lines.—Two trains of 12 wagons will work simultaneously—



Calling one line A, B, C, D in imaginary sections of 80 yards, the other L, M, N, O, one train will stand at A while the material of L is loaded into it as above described. The train proceeds to C, and the material of A is loaded into the second train standing at M, the rails, as heaviest to carry, being all loaded into the 2 rear wagons nearest A. The material of B is next loaded direct into the train at M, which train proceeds to O. Similarly the material of M and N is loaded into the 1st train at C, which, being full, goes to the base, or nearest siding, while the second train is being loaded. Every effort must be made to prevent delay at the crossing station, at which point an empty train must be standing in readiness. It will take about twice as long to carry and load the material of A into train standing on M as to load into train directly opposite. Thus the time for loading will be alternately 40 and 50 minutes per train load, or approximately 300 yards of double line per hour.

Single Line Removal.—When removing single line, the most expeditious method is to employ platelayers' lorries, when available. Four or five lorries are required, placed at first beside the line at one rail length interval. Six men are told off per lorry, to push and unload, lift lorry off and on to line, etc.; but these men do not load the lorries. The line is prepared by men in advance, as for double line (see above). Two men with sledge hammers (or six with spanners) are sufficient to keep pace with the work of removal.

Working at rail head :—

Loading lorries, 24 (12 working on each side of lorry).
Bolts and keys, 2 (with sledge hammers).
Unbedding bolts and sleepers, 4 (2 picks and 2 crowbars).

Lorries can be pushed, loaded, over line from which all fishplates and keys are removed.

Each rail length complete (*i.e.*, 2 rails and the sleepers under them, with one pair fishplates, and keys, bolts, etc.) is loaded by the 24 men on to one lorry, which is pushed forward, unloaded at from 200—300 yards distance (distributing rails in 3 heaps, and sleepers along

the side of line), and returns, being derailed near the railhead till required to load again. When 100 yards of line is thus carried forward, the empty train is backed opposite the material, which is loaded up by gangs of 12 men to each rail wagon, 6 men to each sleeper wagon, and 2 men in each wagon packing. 250 yards (one train load) of single line can be removed from the road, lorried forward, and loaded up by 100 men on this system in 90—100 minutes.

(2). *Direct Loading System.*—When lorries are not available, the empty train should be stationed at two rail lengths from the railhead, and move forward by that distance as each section of 2 rail lengths in rear is removed, carried forward by hand, and loaded up. Rails should be loaded into the rear wagons, as heaviest to carry.

Party for this system :—

Preparing road in advance, 2.
Removing remaining keys and bolts, 2.
Unbedding sleepers and rails, 4.
Loading rails, 2 gangs of 12—24 (14 men for rails 30′ long).
Loading sleepers, 10 gangs of 6—60.
Packing in wagons (2 in each), 8 (loading into 4 wagons at a time). Total, 100.

It is not found possible to use a greater number without loss of time, from confusion in working in the small space behind the train, and carrying forward between the sides of the wagon and the fence or cutting. Time taken by this system—250 yards of line (1 train load) is 120—130 minutes, the extra time being entirely due to the long distance (averaging 50 yards) over which the material has to be carried by hand before loading up into wagons.

To avoid this system of work, which is slower and more fatiguing, every effort should be made to obtain or to improvise lorries. On English railways, a lorry will be found at every 2 miles, near the platelayers' hut.

SECTION XI.

SURVEY.

5-INCH MICROMETER TRANSIT THEODOLITE.

Optical Adjustment and Levelling.

The theodolite having been set up the cap is removed from the object glass, and the telescope is adjusted as follows :—

(*a*). *Adjustment for Distinct Vision of the Cross Hairs.*

This depends on the observer's eyesight and will vary with the individual. The *eye-piece* must be moved in or out until the cross hairs are sharply defined.

To do this, some observers turn the telescope on the sky to show up the cross hairs ; others prefer to make this adjustment, while looking at an object on the sky line or with a light background, so that they may adjust the eye-piece to show the hairs clearly when the vision is directed *through* them on to an object beyond, rather than when focussed solely on the hairs.

(*b*). *Focussing the Telescope, and Elimination of Parallax.*

The telescope is now directed on to some distant and well-defined object, and the *object glass* moved in or out until the object appears in sharp focus.

When this has been done, the image formed by the object glass eye-piece should be on the plane of the cross hairs.

To test whether this is the case, move the eye slightly to one side, also up and down, and note if the object appears to move relatively to the hairs. If it does not move there is *no parallax*, and the focus is perfect.

But if there is movement it is due to imperfect focus or *parallax*, which must be eliminated before observing is commenced.

The theodolite is finally *levelled;* the procedure is as follows :—

I. Levelling by graduated level on upper horizontal plate, *i.e.*, by the *bottom level.*

The instrument has three footscrews : call them A, B, and C.

(*a*). Place the graduated level parallel to the footscrew arm A.
With A bring the bubble to approximately the centre of its run.

(*b*). Place the level parallel to B and C.
With B and C bring bubble to approximately the centre of its run (turning screws *inwards* or *outwards together*).

(*c*). Note the reading of one end of bubble, say the adjusting screw end.

(*d*). Turn the level end for end over A.
Note the reading.

(*e*). Take the *algebraic* mean of readings, and by means of B and C, set the bubble to this reading.

(*f*). Return the level to its original position parallel to Arm A, and with A set the bubble at the same mean reading.

The bubble should then read the same in any position, but it may be necessary to repeat the whole operation from (*b*) onward.

If the bubble reads the same in any position, then the plate is *level*, *i.e.*, it turns round a truly vertical axis. For, since the bubble tube maintains a constant inclination to the horizon (this inclination being o when the bubble is in the centre), the plane of motion can have no vertical component, therefore the axis must be vertical.

It is seen, therefore, that it is *not necessary to get the bubble* in the *centre* of its run.

It is however inconvenient to have the bubble nearly off the scale at one end, *in which case only* it should be brought to the centre of its run with the adjusting screw.

II. Levelling by the graduated level attached to the vertical arm, *i.e.*, by the *top level*.

The preceding operation having practically levelled the instrument, a more perfect level is obtained by the use of the more sensitive bubble on the vertical arm (because longer and flatter) which can be brought near the centre of its run with the *clip screw*.

The second operation is similar to the first, *i.e.*, using the footscrews and reading one end of the bubble.

The first operation is carried out owing to the difficulty of using the top bubble in the first instance, on account of its sensitiveness.

The adjusting screws of the top bubble should in no case be used for bringing the bubble to the centre of its run, in levelling—(it is required for vertical collimation adjustment).

Instrumental Adjustments.

If it were possible to construct an absolutely *perfect* instrument, *i.e.*, one with which it could be guaranteed that with the telescope directed on any given object, the correct horizontal and vertical angles would *invariably* be read by the micrometers, no adjustments to the instrument would be required ; but unfortunately such perfection is not attainable, and therefore there must be means provided within the instrument to alter the relative position of its various parts when desired in such a way that it will give accurate results ; in other words it must be provided with the means to put it *in adjustment*.

Every theodolite is subject to various errors of adjustment : they are as follows :—

1. Errors in micrometer microscopes.
2. Dislevelment of the transit axis.
3. Horizontal collimation error.
4. Vertical collimation error.

1. *Errors in Micrometer Microscopes.*—The adjustments to each of the micrometers are four in number :—

(1). V's should be 180° apart.

(2). V's should coincide with hairs when head reads 0 (called *adjustment of head*).

(3). *Run* of hairs from one division of arc to the next should correspond with one complete turn of head.

(4). Parallax must be eliminated.

The adjustments are carried out as follows :—

First focus the hairs until they are clearly defined, by moving the eye-piece gently in or out. Then—

(1). Place the V in one micrometer over the division 360°. Note the position of the V in the other micrometer ; if it is not over the 180° division, place it so by means of the middle screw in the side of the box away from the head.

(2). Place the V by the slow motion screw of the upper plate exactly over a division on the arc. Turn the head until the hairs are over the V and this division. The head should then read 10, or a shade over the 10, say 10+. If it does not, the head can be moved on its spindle to make it do so, by holding the milled nut of the spindle firmly with one hand, whilst turning the wheel on its friction bearing with the other hand.

(3). Turn the head till the hairs traverse to the next arc division. It should have made a complete revolution and be back at 10 or 10+as before. If not the magnification of the microscope is either too small or too large, and requires adjusting. This is done by moving the object glass at the end of the microscope near the arc. The upper clamping ring must be loosened, and the object glass screwed in or out until the proper magnification is obtained. Then refix the clamping ring. Screwing the object glass out increases the size of the field, and *vice versâ*. It is not advisable to attempt this adjustment for very small errors in runs of heads. Owing to the difficulty in moving the object glass the exact distance for small adjustments, it is usual to treat both

micrometers together, and adjust one only so as to cancel the error in the other. Thus, if A micrometer has an error of run of $+5''$, and B of $+7''$, the run of A would be altered $12''$, to give an error of $-7''$. Again, if the ascertained errors were $A+5''$, $B-7''$, it would not be expedient to adjust either micrometer since these errors nearly cancelled one another. The mean error is only $1''$ in a run of $10'$ or $600''$. Since the graduation nearest to the V is always intersected, and so a distance less than half the run is traversed, the maximum error due to run would not exceed $\frac{1}{2}''$.

(4). The microscopes will generally be found set in their bracket holders so that the graduated arcs are in their proper focus, and there is no parallax. If not, loosen the clamping screws of the brackets, until the microscope can be moved in or out to its correct focussing distance from the arc. Reclamp the bracket.

It is obvious that the last two adjustments must be made in conjunction.

2. *Dislevelment of Transit Axis.*—The pivots of the telescope rest in Y's, and for accurate work it is necessary that the axis on which these pivots turn shall be horizontal. A screw will be found under one or sometimes each Y support. By it the Y bearing can be adjusted.

The *striding level* is placed on the pivots. Each foot must rest on each pivot evenly, at two points. If one leg of the level is out of adjustment, the level may rest on three points instead of four. This seldom happens; but when it does, adjustment can be made by releasing the screws which attach the legs to the tube. Then turn the legs gently until parallel, and until it is found that the bubble remains stationary when the level is inclined a little on one side or the other of true verticality.

Assuming the striding level in adjustment as to the bearing of its feet, and in position on the axis, select one end of the bubble to work with, say the adjusting screw end. Read this end, say 8. Reverse the level on the pivots end for end and read the same end again, say 6. Then the dislevelment of the pivot axis is $\frac{8-6}{2} = 1$ bubble

division. By means of the screw under one of the Y bearings raise or lower this bearing till the screw end of the bubble reads the mean, viz., 7. Reverse the striding level again, when the screw end should read 7. If not repeat the adjustment to the fresh mean and continue until the screw end of the bubble remains at the same reading when reversed.

Should much difficulty be experienced in securing this steady position of the screw end when the level is reversed, the bearing of the legs on the pivots should be carefully examined. It is not necessary that the bubble should be in the centre of its run ; but it can, if desired, be moved to that position by its adjustment screw *after* the transit axis has been levelled.

3. *Horizontal Collimation.*—The "line of collimation," *i.e.*, the imaginary line from the intersection of the cross hairs to the centre of the object glass, should cut the axis of vertical motion (the transit axis) at right angles.

In order to eliminate the error in the instrument the following procedure is adopted :—

Carefully level the theodolite.

Clamp the bottom plate.

Intersect a suitable object with the vertical hair. Read and book angle on, say, micro. A.

e.g.—

	A Micro.			
F.R.	79	15	38	
Add	180	0	0	
	259	15	38	.....(i.).

Change face.

Intersect object again.

Read and book angle on micro. A.

e.g.—

	A Micro.			
F.L.	259	36	40	.....(ii.).
from (i.)— F.R.	259	15	38	
2 |	518	52	18	
mean	259	26	9	.....(iii.).

Set instrument to read this mean (iii.).

The instrument is set thus :—

Place the micrometer head to read 6′ 9″.

Turn the slow-motion screw of the upper horizontal plate till the V is just beyond the 259° 20′. Then the micro. hairs will be nearly over a division. Continue to turn the slow-motion screw until they are over. The instrument then reads 259° 26′ 9″ as desired. But, operating the slow-motion screw to set the V to the mean angle has now moved the vertical hair off the object. Bring it on again by moving the diaphragm by its horizontal screws.

If these operations have been correctly done, the horizontal error of collimation has been eliminated, and this can be tested by changing face and reading again, when you should get reading (iii.) less 180°, viz. :—

A Micro.

F.R. 79 26 9 ..... (iv.).

If not and you get say—

A Micro.

F.R. 79 26 31 ..... (v.).

take the mean of (iv.) and (v.) and proceed as before.

4. *Vertical Collimation.*—Level the horizontal plate by one end of the upper bubble as already described. Then by the clip screw "*c*" move the bubble to approximately the centre of its run.

With face right intersect with the horizontal hair a suitable distant object such as the top of a spire or pole on the sky-line, and book the reading on one of the micrometers, say :—

	C Micro.	Reduced Angle.		Level Graduations. Eye-end. (E.).	Object-end. (O.).
F.R.	354° 18′ 20″	5° 41′ 40″	+	14	12

Change face and intersect again, and book thus :—

	C micro.				
F.L.	185° 21′ 10″	5° 21′ 10″	+	15	11
	Sums 2	10° 62′ 50″		29	23
	Mean angle =	5° 31′ 25″			

Correct for the bubble ; and, as the angle is elevation, the correction is—

$$+\frac{O-E}{4} \times \text{value of bubble division (say } 5'')$$

$$=\frac{-6}{4} \times 5'' = -7{\cdot}5''$$

Therefore the correct angle is—

$$\begin{array}{r} 5^\circ\ 31'\ 25'' \\ -\ \ 7{\cdot}5'' \\ \hline 5^\circ\ 31'\ 17{\cdot}5'' \end{array}$$

This means a reading on F.L. of 185° 31′ 17·5″ for C vernier.

Set the C micro. to read 185° 31′ 17·5″ by the slow-motion screw "*a*." This will move the hair off the object. Bring the hair on the object again by the clip screw "*c*." This will move the bubble away from the centre of its run, and will also turn the line of micros. Bring the bubble back to the centre of its run by its adjusting screw "*d*." The instrument is then adjusted, but the process should be repeated to make sure. Take F.L. 185° 31′ 17·5″ as the first entry of a new series, book E and O, change face and proceed generally as before.

NOTE.—The adjustment for the 5″ Transit Theodolite is similar to the above, except that the micrometer error adjustments are not made and that in *horizontal* and *vertical* collimation the means are set by the vernier.

LEVEL.

ADJUSTMENTS.

Y and Cooke's Reversible.

Adjustments should be made in the following order :—

(i.). Eliminate parallax.

(ii.). Adjust for collimation, *i.e.*, make line of bottom of Y's or axis of socket (Cooke's) parallel to line of sight.

(iii.). Make both lines in (ii.) parallel to horizontal plate, *i.e.*, perpendicular to axis of rotation.

(iv.). Make line of axis of bubble parallel to all three in (iii.).

COLLIMATION.

1. (*a*). *For Y Level.*—Open the Y's carefully. See that the horizontal hair is still bisecting the object. Revolve the telescope in the Y's gently half a revolution, so that the horizontal hair is turned over, and is again horizontal. If the hair again intersects the object as before, there is no collimation error. But if it is now above, or below it, this error amounts to half the displacement. With the foot screw A, correct one-half this displacement, bringing the horizontal hair, as nearly as you can judge, halfway to the object. Bring the horizontal hair across the remaining half, and so on the object, by means of the diaphragm vertical screws. To make sure of the adjustment, repeat it by revolving the telescope halfway, and proceeding as before. The other hair can now be adjusted by the same process, by turning the telescope quarter way round, and treating it like the first hair. It is not strictly necessary to adjust the vertical hair; but if you adjust both hairs, do last the one you will use as a horizontal hair.

(*b*). *Cooke's Level.*—The adjustment is the same as for the Y level, the telescope being revolved in the socket after the fixing screw is withdrawn. There is only one hair.

2. (*a*). *Y Level.*—To make the line of sight, and the bottom of the Y's (which have been made parallel) both parallel to the horizontal plate. Unclamp the horizontal plate, intersect the object as before. Lift the telescope gently from the Y's, and turn it end for end in the Y's. Again sight the object, by turning the horizontal plate 180°. If the horizontal hair no longer intersects the object, the error is half the displacement. Correct it by bringing the horizontal hair halfway to the object by the foot screw A, and the remainder of the way, *i.e.*, to intersect the object, by the capstan screw (on one of the Y's). As a check, reverse the telescope again, and take another reading to the object, and continue as before, until the error has been eliminated.

(*b*). With Cooke's level, the telescope is withdrawn from and reversed in the socket as carefully as possible, the

socket taking the place of the Y's. Otherwise this adjustment is as for the Y level.

3. To level the instrument.

(i.). Move the legs until the instrument is as approximately level as the eye can judge. It may have been tilted backwards, or forwards, for the previous adjustments.

(ii.). Place the telescope over foot screw A, and turn the latter until the bubble is in the centre of its run. Turn the telescope a right angle over the foot screws B and C, and with the latter, again bring the bubble to the centre of its run. Now note one end of the bubble only, viz.: the end next to the bubble's adjustment screw. Read the number of the divisions on the glass at the end of the bubble, say 6th; revolve the telescope 180, *i.e.*, end for end over B and C, and read the screw end of the bubble again, say 7th division. Then calculate the mean position, viz.: $\frac{6 \times 7}{2} = 6\frac{1}{2}$, and with B and C, move the screw end of the bubble to $6\frac{1}{2}$. Turn the telescope 90° over A, and with that screw, bring the screw end of the bubble to $6\frac{1}{2}$. The screw end of the bubble should now remain at $6\frac{1}{2}$ for any position of the telescope when revolved. It is generally necessary, however, to go through the process once more. The telescope is placed over B and C again, and then reversed over B and C. The screw end of the bubble is read each time, and is set at the fresh mean of the two new readings. The telescope is placed over A, and the screw end of the bubble is made to read this new mean. This process must be continued until the position of the screw end of the bubble is found, at which it remains steady for any position of the telescope. The horizontal plate must be level, when a bubble gives the same reading at one end for any position of the plate. Having got the horizontal plate level, get the axis of the bubble parallel to it, by moving the bubble into the centre of its run, by means of its adjusting screw. Both the horizontal plate and axis of the bubble are then level, and are, therefore, parallel. All instruments should be levelled

by reading one end of the bubble as described above, and setting of the bubble to centre of run be done afterwards. This method is the quickest, and saves the damage to the instrument that is often done when the adjusting screws of the bubble are worn by the trial and error adjustments of other systems. It is quite unnecessary for first levelling an instrument to alter the bubble setting to the centre of its run, unless the bubble case has been so much displaced that the bubble will not float freely within the scale when turned end for end, but is jammed up to one end. Commence operations by placing it there (by means of the foot screws), because you do not yet know what the proper bubble reading is for its present setting, when the horizontal plate is level. The centre position does as well for a start as any other, and ensures a free movement of the bubble.

Level.—Dumpy Pattern.

Adjustments.

Adjustment for Parallax.—As for Y level.

1. *To Level the Instrument and Make Axis of Bubble Parallel to Horizontal Plate.*—As for Y level.

2. *Adjustment for Collimation.*—To set the line of collimation (*i.e.*, the line joining the optical centre of the object glass, and the intersection of the cross wires) parallel to the horizontal plate.

Select a level piece of ground, and drive two pickets, A and B, about a chain distant on either side of the instrument.

Having carefully levelled the instrument and adjusted bubble axis, as in 9, place a levelling staff on A (if the lower picket) and read the staff. Turn the telescope, and read the staff now placed on B, drive the picket until the reading on the staff is the same as in the first case. The pickets A and B will now be on the same level (see *Fig.* 1). Now place the level half a chain beyond either picket, and level the instrument (see *Fig.* 2). Read the staff on A and B in turn, and if the readings are not the same, make them so by using the diaphragm screws only.

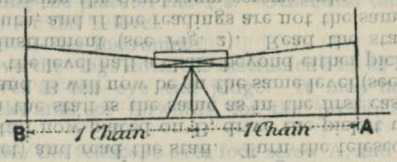


FIG. 1.

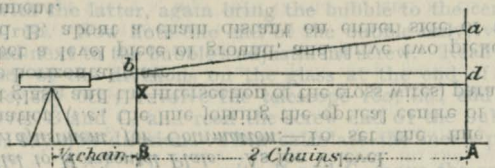


FIG. 2.

TRIGONOMETRICAL SURVEY.

Base Line.

Expansion of iron or steel chain or tape = 0·0000063 58′ per 1° F.

Measured length × sine inclination = difference of level.

Measured length × cosine inclination = horizontal distance.

Satellite Stations.

The correction for observed angles referred to "centre" may be found as follows:—

d = distance to "centre."

l = roughly computed distance to point observed.

A = observed angle referred to "centre."

x = correction required.

Then $\sin x = \frac{d \times \sin A}{l}$.

or, if tables giving logarithms of trigonometrical functions to 1″ are not available,

$$\text{the number of seconds in } x = \frac{d \times \sin A}{l \times \sin 1''}, \quad (\text{L sin } 1'' = 4{\cdot}68557).$$

Triangulation.

In any triangle A B C, a being the known, and b and c the unknown sides—

$$b = a \sin B \operatorname{cosec} A.$$
$$c = a \sin C \operatorname{cosec} A.$$

Difference of Level between Stations.

It being assumed that reciprocal vertical angles are taken between stations, which eliminates all corrections for curvature and refraction,

If A is the station of which the height is known.

B ,, ,, ,, ,, required.

C = Distance in feet between A and B.

g_a = Height of signal at A above ground.

g_b = ,, ,, B ,, ,,

D_a = Vertical angle of depression at A.

D_b = ,, ,, B.

E_a = ,, ,, elevation at A.

E_b = ,, ,, B.

i_a = Height of instrument above ground at A.

i_b = ,, ,, B.

Height of B = Height of A

$$+ C \tan S + \frac{g_a - g_b + i_a - i_b}{2}$$

where $S = \frac{D_b - D_a}{2}$.

If either angle is an elevation it is to be treated as a *negative* quantity in above formula.

If *one angle only is observed*—

$$S = K - D \text{ or } K + E,$$

where K can be formed from the following table :—

Distance between stations in feet.	K.		Distance between Stations in feet.	K.		Distance between Stations in feet.	K.	
	′	″		′	″		′	″
1000	0	4	8000	0	34	50000	3	33
2000	0	9	9000	0	38	60000	4	15
3000	0	13	10000	0	43	70000	4	58
4000	0	17	20000	1	25	80000	5	40
5000	0	21	30000	2	8	90000	6	23
6000	0	26	40000	2	50	100000	7	5
7000	0	30						

Chain Survey.

The length of a chain is counted from centre to centre of handles, or in practice, from the inside of the leading handle to the outside of the following handle : this eliminates the error of the diameter of the arrow and avoids the displacement of the back arrow.

All chaining should be carried out horizontally, not along the surface of the ground, and down hill in preference to up hill. On steep slopes ½ or ¼ chain can be used at a time, the rule being not to allow any part of the chain to be more than 4′ from the ground.

The error in a chained line should not exceed 2 links per 1,000.

If an insuperable obstacle prevents chaining in a direct line, the difficulty can be got over as follows :—

(1). *If the Line of Sight is not Impeded.*—Chain A B (*Fig.* 1) twice as long as necessary to clear the obstacle, and B C to any point on the line beyond the obstacle ; bisect A B and B C in D and E, measure D E, then A C = 2 × D E.

Or, produce A B, C B to F and G, making B F = A B, and B G = C B, then G F = A C.

(2). *If the Line of Sight is Impeded.*—At 4 or 5 chains from the obstacle, set up a perpendicular B C (*Fig.* 2) long enough to clear it; close to the obstacle set up another perpendicular D E equal to B C, then chain along

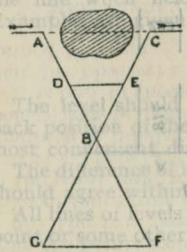


FIG. 1.

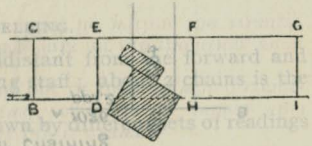


FIG. 2.

the line C E produced, till clear of the obstacle, and drop two perpendiculars F H, G I, each equal to B C or D E; E F=D H, and the points H, I, will give the alignment beyond the obstacle; E F being also evidently parallel to D H, any offsets taken from it can be reduced to their value as if taken from D H.

Many of the methods given under "MEASUREMENT OF HEIGHTS AND DISTANCES" can also be employed in special cases.

The length of offset allowable depends on the scale to which the work is to be plotted; a useful limit is that no offset should plot to more than from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch. Beyond this limit, to fix *important* points, the distance may be measured from two points in the chained line sufficiently far apart to give a good intersection.

Field-Book.

Detail crossing the chained line obliquely should be shown as in *Fig.* 3, not as in *Fig.* 4.

The recognized method of identification should be used in entering the work, viz., apices of main triangles by

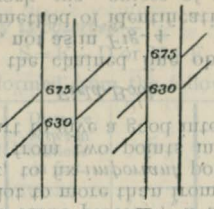
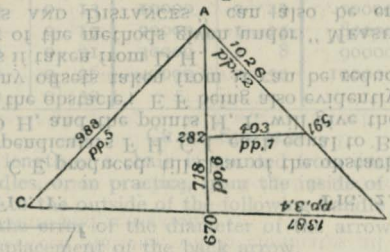


FIG. 3. FIG. 4.

Line Diagram.



Detail of Chaining

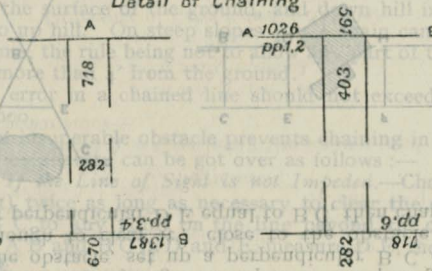


FIG. 5.

letters, lines by their measured length in links (written over them in the direction in which chaining has been carried out), intermediate points on lines by their distance from the initial point of the line (written perpendicular to the line when held with the initial point below), etc. Examples are given in *Fig.* 5.

Levelling.

The level should be equidistant from the forward and back position of the levelling staff; about 2 chains is the most convenient distance.

The difference of level shown by different sets of readings should agree within 0'·01.

All lines of levels should be closed either on the starting point or some other point whose relative level is known.

Traversing with the Theodolite.

The traverse should be frequently checked by observing the reading of the magnetic needle. This varies by 180° at alternate stations.

Chaining is carried along the surface of the ground, the inclination being taken with the theodolite. Offsets are taken in the usual way.

If the closing point can be seen from the starting point, a reading should be taken to it on commencing the traverse, which can then be closed on the starting point by a reading to it from the closing point.

Contouring.

The most suitable method for contour lines over long distances, at a considerable vertical interval, is to run a traverse along the contour.

For areas with contours at short vertical intervals it is better to run a line of levels along the boundaries, fixing the ends of the different contours, and the intermediate points can then be pegged out from one or more positions with a level and surveyed with a chain and offset rod.

When drawing short rays, from which it may afterwards be necessary to set the board, it is advisable to make "repere" marks as near the margin as the length of the ruler will allow.

Interpolation.

The following is the best method of interpolation on a plane-table by re-section from three known points :—

Set up the table by the compass, and draw back rays from the three known points. If these intersect in a point, it is the required position. If not, the three rays will form a small triangle, called the triangle of error. The exact position can then be fixed as follows :—

(*a*). If the "triangle of error" lies between the triangle formed by joining the three known points, the true position is within the "triangle of error." If the "triangle of error" lies outside the triangle, the true position will be outside the "triangle of error," in one of the segments formed by its sides produced, in which the perpendiculars to it from the three rays are either each to the right (or each to the left) of their respective rays when viewed from the points from which the rays are drawn.

(*b*). The true position must be such that its perpendicular distance from each ray is proportional to the distance of the point from which that ray is drawn.

N.B.—There are only two segments in which this condition is fulfilled, and only one of these in which condition (*b*) can be fulfilled.

It is best to choose known points for interpolation, such that the observer's position shall lie within the triangle formed by them.

MEASUREMENT OF HEIGHTS AND DISTANCES.

(*For Short Distances*).

Heights.

With Instruments (*Fig.* 6).

(1). If the point is accessible—

AB = BC tan A*cb* + height of observer's eye.

(2). If inaccessible—

$$AB = \frac{DC}{\cot Adb - \cot Acb} + \text{height of observer's eye.}$$

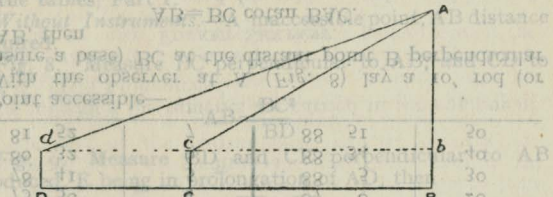


FIG. 6.

Without Instruments.—The above assume the ground to be level, and on such ground fairly good results can be obtained as follows :—

(1). If the point is accessible—

Set up a rod of known length vertically at G (*Fig.* 7), and mark on it the height of the eye *g*, step back a few paces and note or mark a point *b* in the line of sight coinciding with the mark *g* on the rod, now step back to

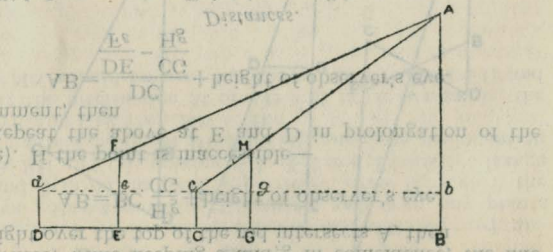


FIG. 7.

C, where, while keeping b and g in coincidence, the line of sight over the top of the rod intersects A, then

$$AB = BC \frac{Hg}{CG} + \text{height of observer's eye.}$$

(2). If the point is inaccessible—

Repeat the above at E and D in prolongation of the alignment, then

$$AB = \frac{DC}{\frac{DE}{Fe} - \frac{CG}{Hg}} + \text{height of observer's eye.}$$

Distances.

With Instruments.—Point inaccessible.

See *Fig.* 8.

$$AB = BC \tan BCA.$$

The following angles give the distance (AB) in integral multiples of the base (BC):—

Angle.	Multiplier.	Angle.	Multiplier.
° ′		° ′	
45	1	82 52	8
63 26	2	83 40	9
71 34	3	84 17	10
75 58	4	87 8	20
78 41	5	88 5	30
80 32	6	88 34	40
81 52	7	88 51	50

Point accessible—

With the observer at A (*Fig.* 8) lay a 10′ rod (or measure a base) BC at the distant point B perpendicular to AB, then

$$AB = BC \operatorname{cotan} BAC.$$

With a 10′ rod and theodolite the distance can be found by this method with great accuracy by taking the angle several times, turning the plates back *together* between each reading, so that the total reading shown on the horizontal arc is the sum of the readings taken;

this total, divided by the number of readings, will give the angle with considerably greater minuteness than the graduation of the scale. Natural cotangents will be found in the tables, Part I.

Without Instruments.—A inaccessible point, AB distance required.

Fig. 8. Measure BC perpendicular to AB, and CD to AC.

$$AB = \frac{BC^2}{BD}.$$

Fig. 9. Measure BD and CE perpendicular to AB produced, E being in prolongation of AD, then

$$AB = \frac{BD \times BC}{CE - BD}.$$

Fig. 10. Join D in AB produced with any convenient point C, bisect DC in E, join BE and produce to F, making EF equal to BE, range G in line with AE and CF, then AB = FG.

FIG. 8.

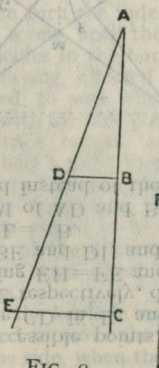


FIG. 9.

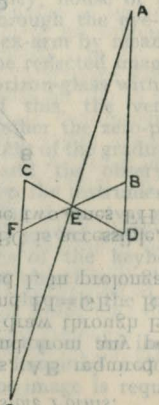


FIG. 10.

Distance between Two Inaccessible Points.

Fig. 11. A, B, inaccessible points, AB required distance. Bisect any line CD in E, and from any points F and G in AD and BC respectively, draw through E the lines FH and GI, making EH=FE and EI=GE. Range K in prolongation of BE and DI, and L in prolongation of AE and CH, then KL=AB.

(If the intersection M of AD and BC is accessible, the line MN should be used instead of the two lines FH and GI).

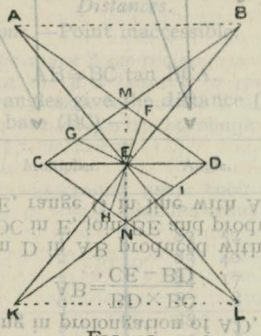


FIG. 11.

The following instruments are carried in the equipment of R.E. Field Companies:—

POCKET SEXTANT.

This instrument is used for taking angles within 130° upon the surface of the land to within a single minute of arc.

When required for use, the case should be unscrewed, the telescope pulled out to its full extent, and the small

slide at the underpart of the sextant pushed back; the dark glasses can then be pressed down through the opening by means of a pair of levers at the side of the instrument. The lid should then be reversed, and screwed on to the lower part of the sextant.

To take an angle, the observer either looks through the telescope or hole in the side, at the left-hand object, holding the sextant horizontal in his left hand; with his right he turns the milled-headed screw until the other object reflected from the index-glass appears upon the silvered part of the horizon-glass, exactly covering or agreeing with the left-hand object, seen direct through the unsilvered portion of the horizon-glass; the angle is then read off the graduated arc.

Index Error.

The most simple method to determine this is to select some distant object, such as a chimney, house or flag-staff, and then look at the object through the eye-hole and horizon-glass. Then turn the index-arm by means of the large milled-headed screw, until the reflected image of the selected object coincides in the horizon-glass with the object seen direct. Having effected this, the vernier should then be examined, to note whether the zero-point of the vernier coincides with the zero-point of the graduated scale. If this coincidence occurs, and the observer's object be distant fully half a mile, then the instrument is in adjustment, and ready for use; but if the two zero-points do not agree, the index-arm is moved until they do, and the key is then placed in one of the keyholes, and the reflected image of the distant object is made to coincide with the object seen direct through the lower part of the horizon-glass.

The key is inserted in the keyhole on top of the instrument, when it is required to move the image up or down, and in the keyhole at the side, when the image is required to be moved to the right or left.

De Lisle's Clinometer.

This instrument is used principally for laying out grades. It can also be used for determining road gradients.

A heavy arc is constructed upon the lower part of the instrument, which is jointed upon a vertical axis so that it may be revolved to bring the mass of the arc either forward or backward, to take inclines upwards or downwards, or to rest at an intermediate position to make the instrument flat and portable in its case.

The arc has a stiff centre axis with a radial bar, the edge of which forms the index. A sliding weight is placed on the radial bar, which is of sufficient weight when slid out to its greatest extension to exactly counterbalance the weight of the arc in a horizontal position and to make the mirror quite vertical. A set of gradations are engraved upon the arc, which are numbered 1 to 50. The radial bar index set to one of these gives the amount of inclination that will result from coincidence of the reflection of the centre of the pupil of the eye cutting the object to be observed. When used for slopes the counterweight should not be pulled out and the word LEVEL should not be visible.

To Use the Instrument.

(*a*). *For Grading Roads.*—Set the radial bar to the gradient required, then fix a crosspiece on a staff to the height of the observer's eye. The observer then sends the staff man forward to a certain point; arrived there he grounds his staff and looks for signals from the observer, who waves him to go more up hill or down until the distant cross-staff head coincides with the eye-image on the clinometer mirror. If the grade is to be continued the observer goes on to some convenient point beyond No. 1, sending his second cross-staff still further ahead. A sight is then taken back to No. 1, the observer shifting his own position until he gets on the grade, then forward to the next cross-staff, who is, like No. 1 was, shifted about until he gets on the line.

(*b*). *For Taking Gradients.*—If used for taking gradients the staff adjusted to the height of the observer's eye would be placed forward and the inclination lever moved until the eye and staff coincide.

Level, Pocket (Abney).

The observer holds the level in his left hand, and focusses the telescope, making the hair in the body of the reflector holder bisect the point required. Then still looking through the telescope, with the right hand turn the milled-headed screw at top of instrument until the reflection of the bubble is seen to bisect the index mark on the reflector.

The angle is then read off the graduated arc.

De Lisle's Clinometer.

This instrument is used principally for laying out grades. It can also be used for determining road gradients.

A heavy arc is constructed upon the lower part of the instrument, which is jointed upon a vertical axis so that it may be revolved to bring the mass of the arc either forward or backward, to take inclines upwards or downwards, or to rest at an intermediate position to make the instrument flat and portable in its case.

The arc has a stuff centre axis with a radial bar, the edge of which forms the index. A sliding weight is placed on the radial bar, which is of sufficient weight when slid out to its greatest extension to exactly counterbalance the weight of the arc in a horizontal position and to make the mirror quite vertical. A set of gradations are engraved upon the arc, which are numbered 1 to 50. The radial bar index set to one of these gives the amount of inclination that will result from coincidence of the reflection of the centre of the pupil of the eye cutting the object to be observed. When used for slopes the counterweight should not be pulled out and the word LEVEL should not be visible.

To Use the Instrument.

(*a*). *For Grading Roads.*—Set the radial bar to the [illegible] on the graduated arc. [illegible] observer sights [illegible] reflector.

The mark is then read on the graduated arc.

(*b*). *For Laying Gradients.*—If used for laying gradients the mark is to be placed to the height of the operator's eye below that of the instrument level, the bar [illegible] the eye bar [illegible]

LEVEL POCKET (VARLEY).

The operator holds the level in his left hand, the focusses the telescope making the part in the body of the reflector [illegible] Then slip [illegible] holder press the point reduced. [illegible] rotate the telescope through the reflector, with the right hand the reflection of the pupil is seen to press the index mark on [illegible] bubble-bended across. When in position to get [illegible] instrument with the reflection

SECTION XII.

ASTRONOMY.

Adjustments of Instruments.

These are given in the order in which they should be carried out, and they should be repeated till perfect in each case.

Sextant.

(1). *To Set Index Glass Perpendicular to Plane of Sextant.*—With the Index Arm near the middle of the arc and the eye near the Index Glass, observe whether the Arc, seen directly, and its reflected image in the Index Glass, appear to form one continuous arc; if not, adjust the Index Glass by the small screws that fix the plate which carries it.

(2). *To Set Horizon Glass Perpendicular to Plane of Sextant.*—Direct the telescope on a Star, and move the Index Arm until the reflected image of the Star appears to pass the direct image. If one image passes on either side of the other, adjust by means of the small screw provided for the purpose until one image passes exactly over, or, if preferred, just clear of the other.

(3). *To Set Sight-Line of Telescope Parallel to Plane of Sextant.*—With two of the telescope wires parallel to the plane of the sextant, make contact on or near one wire between two stars, then, keeping the Index Arm clamped, move the sextant till they appear on the other wire. If not now in contact, adjust by means of the two small opposing screws in the ring which carries the telescope.

(4). *Index Correction.*—When contact is made between the direct and reflected images of an object on which the telescope is directed, the vernier should read zero, and

can be made to do so by means of the adjusting screw at the back of the Index Glass. It is better, however, to note the error for correction of the observed readings; this should be done both before and after a set of readings.

(*a*). With the Sun.—Direct the telescope on the Sun, and note the readings of both upper and lower limb contacts, then the correction is

$$\frac{\text{Reading off the arc} - \text{Reading on the arc}}{2}.$$

The correction is additive or subtractive, according to the sign of the fraction, and its accuracy can be checked by comparing $\frac{1}{2}$ the sum of the two readings with the Sun's Semi-diameter for the day.

(*b*). With a Star.—The reading of the vernier when contact is made between the direct and reflected image is the index correction, additive if off the arc (*i.e.*, on the arc of excess), subtractive if on the arc.

Transit Theodolite.

The adjustments of this are the same, with the following modifications, as for the theodolite (see Section XII. *Survey and Reconnaissance*):—

In the adjustment of the vertical arc, instead of reversing the telescope in its bearings, it is turned on its trunnions through 180°.

With the sensitive bubble attached to the Vertical Arc, it is not practically possible to work with the bubble exactly in the centre, but both ends of the bubble should be within the limits of the bubble scale, and the value of each division of the bubble scale is determined by observation of a distant object with the bubble in various positions. The readings of the two ends of the bubble are noted as "Object end" and "Eye end" for each observation taken, and the observed angle corrected accordingly. If the "Object end" has the greater reading, the correction must be added to the altitude observed, and *vice versâ*.

A striding level is provided to test the horizontality of the axis of the trunnions; this must be placed direct on

the trunnions themselves, and read in reversed positions (end for end) to eliminate errors in the level itself, and the telescope must also be reversed in its bearings in case of difference in diameter of the two trunnions. The bearings are adjusted by the screws fixing the sliding wedge of one of them.

Observing.

It is preferable to take readings of the upper and lower limbs of the Sun alternately rather than to use the correction for Semi-diameter.

Dark glasses should be chosen with due regard to the intensity of the object observed, so that the image may be sufficiently faint not to fatigue the eye.

It is a good plan, when possible, to set the readings in advance to equal angular intervals, and wait for contact to be made by the Sun's (or Star's) own motion.

To note the time of observation without an assistant, having ascertained the number of beats that the watch makes to a convenient integral number of seconds, place it where it can easily be seen and the beats distinctly heard. From the moment of contact begin to count the beats, turning the head at the same time towards the watch, and note the time indicated at the required beat; subtracting the number of seconds equivalent to the number of beats counted will give the true time of contact.

With the Theodolite.

The telescope should be reversed between each observation or set of observations.

In observations for Azimuth, the Referring Object should be read before and after each set of observations.

The readings of both ends of the bubble of the Vertical Arc should be taken at each observation for altitudes.

When observing at night, the wires should be sufficiently illuminated to make them distinctly visible without obscuring the Star to be observed. This can be done by reflecting the rays from a bull's-eye lamp down the telescope from a small strip of white paper fixed in an inclined position in front of the Object Glass.

With the Sextant.

Keeping the telescope wires parallel and perpendicular to the plane of the instrument is an assistance in holding it upright when observing.

In observing objects of different degrees of brightness, the dark glasses should be arranged so that the images as seen should be of the same intensity ; for the same reason the telescope should be directed on the fainter of the two objects. Thus, when observing altitudes with the artificial horizon, the telescope should be directed on the image seen in the artificial horizon.

It is preferable to use the dark glass on the eye-piece to those in front of the two mirrors, as the latter may introduce an error through possible difference in refraction through the two glasses.

The glass cover of the artificial horizon should be reversed between each observation.

With an inverting telescope, the image seen in the artificial horizon is an erect image.

Comparison of Timekeepers.

Clocks and chronometers are compared by noting coincident beats, and comparison should always be made between two, regulated, the one to Mean, and the other to Sidereal time, as the beats will then coincide every three to six minutes, according to whether they beat half-seconds or seconds.

Reduction of Observed Altitudes.

Corrections have to be made in the following order to all observed altitudes before they can be used in calculations :—

(1). Index and instrumental corrections.

(2). Reduction from double to single altitude (if taken with the sextant).

(3). Correction for refraction (corrected for temperature and barometric pressure).

(4). Correction for semi-diameter (for sun and moon only).

(5). Correction for parallax (for sun and moon only).

Symbols.

ϕ = Latitude.
δ = Declination at time of observation.
δ' = Declination on the meridian.
p = Polar distance.
α = Right ascension.
h = Altitude.
ζ = Zenith distance at time of observation.
ζ' = Meridian zenith distance.
ζ_0 = Mean of zenith distances at times of observations.
A = Azimuth.
HA = Hour angle expressed in time.
t = Hour angle expressed in arc.
AT = Apparent time.
MT = Mean time.
ST = Sidereal time.
L = Local.
G = Greenwich.
N = Noon.
E = Equation of time.
I = Interval.

Conversion of Intervals and Time.

Mean Interval = Sidereal Interval − 9·8296 seconds for each hour of Sidereal Interval.

Sidereal Interval = Mean Interval + 9·8565 seconds for each hour of Mean Interval.

Tables to facilitate this process are given at the end of the *Nautical Almanac* and elsewhere.

Sidereal into Mean Time.—From the given Sidereal Time (+24 hours, if necessary) subtract the LST of the preceding LMN (reduced from the GST of GMN by adding 9·8565 seconds for each hour of West Longitude), and convert the difference into its Mean equivalent.

Mean into Sidereal Time.—From the given Mean Time (+24 hours, if necessary) subtract the LMT of LSN (reduced from the GMT of GSN by subtracting 9·8296

seconds for each hour of West Longitude), and convert the difference into its Sidereal equivalent.

Greenwich Mean Time into Local Mean Time.—If the locality is East, add, if West, subtract the Longitude in hours, minutes and seconds.

Mean and Apparent Time.—If E be the Equation of time at any particular instant (taken as + when additive to apparent time)—

$$MT = AT + E \text{ and } AT = MT - E.$$

Hour Angle and Time.—

With the Sun—

$$HA = AT.$$

With a Star—

$$HA = ST \ (+24 \text{ hours, if necessary}) - \alpha.$$

Time.

By Transit.

In the case of the Sun, the time of transit is Local Apparent Noon; with a Star, the Right Ascension of the Star is the Sidereal Time of Transit.

Correction for Level Error $= \frac{S \cos \zeta}{\cos \delta}$, where S = the inclination of the axis, corrected for inequality of pivots. For an upper transit this correction is + when the west pivot is the higher, and – when the east pivot is the higher; the reverse for lower transits.

Correction for Collimation Error

$$= \text{Collimation constant} \times \sec \delta.$$

Correction for Azimuth Error

$$= \text{Azimuthal constant} \times \frac{\sin \zeta}{\cos \delta}.$$

The Equatorial Intervals of the wires are best found by noting the times of transit of a circum-polar star over them; the intervals between these $\times \cos \delta$ give the "Equatorial Intervals." The Interval for any particular star = Equatorial Interval $\times \sec \delta$ of that star.

By Single Altitudes of Sun or Star.

$$\sin\frac{t}{2}=\sqrt{\frac{\sin\frac{1}{2}(\zeta+\phi-\delta)\sin\frac{1}{2}(\zeta-\phi-\delta)}{\cos\phi\cos\delta}}$$

or $$\tan\frac{t}{2}=\sqrt{\frac{\cos s\sin s-h}{\cos s-p\sin s-\phi}},$$

The observations should be taken as near the Prime Vertical as possible, and with stars, two stars of approximately equal altitude, one east and the other west of the meridian, should be taken, and the results combined.

LATITUDE.

By a Meridian Altitude.

$$\phi=\zeta'+\delta \text{ or } \delta-\zeta',$$

according to whether the Zenith is north or south of the Star.

By a Single Ex-Meridian Altitude.

$$\tan m=\cos t\cot\delta,$$

$$\sin(m+\phi)=\cos\zeta\cos m\operatorname{cosec}\delta.$$

By Circum-Meridian Altitudes.

$\phi=Z+\delta$ or $\delta-Z$,

$Z=\zeta_0-Am_0$ (for upper transits), and

$Z=\zeta_0+Am_0$ (for lower transits),

where $A=\dfrac{\cos\phi\cos\delta}{\sin\zeta'}$,

$m_0=$ the mean of $\dfrac{2\sin^2\frac{t}{2}}{\sin 1''}$ for the several observations.

For tables of values of m see end of this Section.

By Single Altitudes of Polaris.

$$\phi = h - p \cos t + \tfrac{1}{2} p^2 \sin 1'' \sin^2 t \tan h.$$

It can also be worked out by means of the tables given in the *Nautical Almanac* for the purpose.

Longitude.

It will not often happen that an officer has to determine longitude on service; if he has to, he should remember that the following is approximately the order of accuracy of the various methods.

Table showing the errors which might be expected in a march of 300 miles in a hilly tropical country :—

Method.	Probable Error in Longitude.
1. Triangulation	100 yards to $\frac{1}{4}$ of mile.
2. Latitudes and azimuths...	$\frac{1}{4}$ mile.
3. Telegraph.....	$\frac{1}{4}$ mile.
4. Occultation	1 mile.
5. Chronometers (5)	1 mile.
6. Moon-culminations	5 miles.
7. Lunar distances (1 determination)	Anything over 10 miles.
8. Eclipses	Anything over 10 miles.

It is thus clear that it is better to give up the idea of making a determination by absolute methods, and if triangulation of No. 2 are impossible, try telegraph or transport of chronometers.

Longitude by Telegraph.

This merely consists in the observer at A telegraphing his local time to the observer at B. He should send a signal every 10 seconds (omitting the 50th second) for say 5 minutes. The observer at B notes the times on his chronometer (of which he has previously determined the error and rate). The difference, at the same instant, of the local times at A and B is the difference of longitude in time. B should also send to A. The mean of the two results will eliminate the small error due to the times taken by the current along the wire.

By Comparison of Chronometers.

The difference between the Local Times of two Meridians gives the difference of Longitude in hours, minutes, and seconds, the later time being that of the more easterly meridian.

AZIMUTH.

Azimuth angles being reckoned from the south (+westwards, −eastwards).

If A = Azimuth of the heavenly body,

A' = Azimuth of the terrestrial object or R.O.,

a = difference of Azimuth (+ or − according as the terrestrial object is west or east of the heavenly body),

then $A' = A + a$,

and $A' + 180° =$ true bearing of R.O.

With the Sextant.

$$\tan M = \frac{\tan \delta}{\cos t} \quad \text{.....(i.),}$$

$$\tan A = \frac{\tan t \cos M}{\sin \phi - M} \quad \text{.....(ii.),}$$

$$\tan h \text{ or } \cot \zeta = \cot \phi - M \cos A \quad \text{.....(iii.),}$$

$$\tan^2 \frac{a}{2} = \frac{\sin \overline{s - h'} \sin \overline{s - H}}{\cos s - D \cos s},$$

where H = elevation of the R.O., negative if depression,

h' = apparent altitude of the Sun,

D = observed angle between the Sun and terrestrial object,

and $s = \frac{1}{2}(H + h' + D)$.

The signs of the trigonometrical functions must not be neglected, as they determine the quadrant in which A is.

Azimuth by Sun with the Theodolite.

Method No. 1 (*knowing latitude*).—Observe the angle between the referring mark and the Sun, when it is not more than 30° above the horizon.

Simultaneously intersect with vertical and horizontal wires the Sun's left and lower limbs, say on Face Right. Then intersect right and upper limbs on Face Left. Take the mean altitude, correct for refraction and parallax, let this be h.

Then $\tan \frac{A}{2} = \sqrt{\{\sec s \sec (s-p) \sin (s-\phi) \sin (s-h)\}}$

Method No. 2 (*knowing time and latitude*).—Use formulæ 1 and 2 given for sextant observations.

Azimuth by Altitude of E. or W. Star with the Theodolite.

When the Latitude is known.—Observe the horizontal angle between the Referring Mark and Star and the Star's altitude simultaneously, by getting the Star on the intersection of cross wires of theodolite. Then compute Azimuth by last formula.

By Greatest Elongation of a Circum-Polar Star.

To calculate approximate time of elongation :—

$$\cos t = \tan \phi \cot \delta.$$

To find the azimuth :—

$$\sin A = \cos \delta \sec \phi.$$

Values of m.

Sec.	0m	1m	2m	3m	4m	5m	6m	7m	8m
	″	″	″	″	″	″	″	″	″
0	0·0	2·0	7·8	17·7	31·4	49·1	70·7	96·2	125·7
2	0·0	2·1	8·1	18·1	31·9	49·7	71·5	97·1	126·7
4	0·0	2·2	8·4	18·5	32·5	50·4	72·3	98·0	127·8
6	0·0	2·4	8·7	18·9	33·0	51·1	73·1	99·0	128·8
8	0·0	2·5	8·9	19·3	33·5	51·7	73·9	99·9	129·9
10	0·1	2·7	9·2	19·7	34·1	52·4	74·7	100·8	130·9
12	0·1	2·8	9·5	20·1	34·6	53·1	75·5	101·8	132·0
14	0·1	3·0	9·8	20·5	35·2	53·8	76·3	102·7	133·1
16	0·1	3·1	10·1	20·9	35·7	54·5	77·1	103·7	134·2
18	0·2	3·3	10·4	21·4	36·3	55·1	77·9	104·6	135·3
20	0·2	3·5	10·7	21·8	36·9	55·8	78·8	105·6	136·3
22	0·3	3·7	11·0	22·3	37·4	56·5	79·6	106·6	137·4
24	0·3	3·8	11·3	22·7	38·0	57·3	80·4	107·5	138·5
26	0·4	4·0	11·6	23·1	38·6	58·0	81·3	108·5	139·6
28	0·4	4·2	11·9	23·6	39·2	58·7	82·1	109·5	140·7
30	0·5	4·4	12·3	24·0	39·8	59·4	83·0	110·4	141·8
32	0·6	4·6	12·6	24·5	40·3	60·1	83·8	111·4	143·0
34	0·6	4·8	12·9	25·0	40·9	60·8	84·7	112·4	144·1
36	0·7	5·0	13·3	25·4	41·5	61·6	85·5	113·4	145·2
38	0·8	5·2	13·6	25·9	42·1	62·3	86·4	114·4	146·3
40	0·9	5·4	14·0	26·4	42·8	63·0	87·3	115·4	147·5
42	1·0	5·7	14·3	26·9	43·4	63·8	88·1	116·4	148·6
44	1·1	5·9	14·7	27·4	44·0	64·5	89·0	117·4	149·7
46	1·2	6·1	15·0	27·9	44·6	65·3	89·9	118·4	150·9
48	1·3	6·4	15·4	28·3	45·2	66·0	90·8	119·5	152·0
50	1·4	6·6	15·8	28·8	45·9	66·8	91·7	120·5	153·2
52	1·5	6·8	16·1	29·4	46·5	67·6	92·6	121·5	154·3
54	1·6	7·1	16·5	29·9	47·1	68·3	93·5	122·5	155·5
56	1·7	7·3	16·9	30·4	47·8	69·1	94·4	123·6	156·7
58	1·8	7·6	17·3	30·9	48·4	69·9	95·3	124·6	157·8

Reduction to Meridian.—*Cont.*

Values of m.

Sec.	9m	10m	11m	12m	13m	14m	15m	16m
	″	″	″	″	″	″	″	″
0	159·0	196·3	237·5	282·7	331·7	384·7	441·6	502·5
2	160·2	197·6	239·0	284·3	333·4	386·6	443·6	504·6
4	161·4	198·9	240·4	285·8	335·2	388·4	445·6	506·7
6	162·6	200·3	241·9	287·4	336·9	390·2	447·5	508·8
8	163·8	201·6	243·3	289·0	338·6	392·1	449·5	510·9
10	165·0	202·9	244·8	290·6	340·3	393·9	451·5	513·0
12	166·2	204·2	246·3	292·2	342·0	395·8	453·5	515·1
14	167·4	205·6	247·7	293·8	343·7	397·6	455·5	517·2
16	168·6	206·9	249·2	295·4	345·5	399·5	457·5	519·3
18	169·8	208·3	250·7	297·0	347·2	401·4	459·5	521·5
20	171·0	209·6	252·2	298·6	349·0	403·3	461·5	523·6
22	172·2	211·0	253·6	300·2	350·7	405·1	463·5	525·7
24	173·5	212·3	255·1	301·8	352·5	407·0	465·5	527·9
26	174·7	213·7	256·6	303·5	354·2	408·9	467·5	530·0
28	175·9	215·1	258·1	305·1	356·0	410·8	469·5	532·2
30	177·2	216·4	259·6	306·7	357·7	412·7	471·5	534·3
32	178·4	217·8	261·1	308·4	359·5	414·6	473·6	536·5
34	179·7	219·2	262·6	310·0	361·3	416·5	475·6	538·7
36	180·9	220·6	264·1	311·6	363·1	418·4	477·6	540·8
38	182·2	222·0	265·7	313·3	364·8	420·3	479·7	543·0
40	183·5	223·4	267·2	315·0	366·6	422·2	481·7	545·2
42	184·7	224·8	268·7	316·6	368·4	424·2	483·8	547·4
44	186·0	226·2	270·3	318·3	370·2	426·1	485·8	549·5
46	187·3	227·6	271·8	319·9	372·0	428·0	487·9	551·7
48	188·5	229·0	273·3	321·6	373·8	429·9	490·0	553·9
50	189·8	230·4	274·9	323·3	375·6	431·9	492·0	556·1
52	191·1	231·8	276·4	325·0	377·4	433·8	494·1	558·3
54	192·4	233·2	278·0	326·7	379·3	435·8	496·2	560·5
56	193·7	234·7	279·5	328·4	381·1	437·7	498·3	562·8
58	195·0	236·1	281·1	330·0	382·9	439·7	500·4	565·0

Reduction to Meridian.—*Cont.*

Values of m.

Sec.	17m	18m	19m	20m	21m	22m	23m
	″	″	″	″	″	″	″
0	567·2	635·9	708·4	784·9	865·3	949·6	1037·8
2	569·4	638·2	710·9	787·5	868·0	952·4	1040·0
4	571·6	640·6	713·4	790·1	870·8	955·3	1043·8
6	573·9	642·9	715·9	792·7	873·5	958·2	1046·8
8	576·1	645·3	718·4	795·4	876·3	961·1	1049·8
10	578·4	647·7	720·9	798·0	879·0	963·9	1052·8
12	580·6	650·0	723·4	800·7	881·8	966·9	1055·9
14	582·9	652·4	725·9	803·3	884·6	969·8	1058·9
16	585·1	654·8	728·4	806·0	887·4	972·7	1062·0
18	587·4	657·2	730·9	808·6	890·2	975·6	1065·0
20	589·6	659·6	733·5	811·3	893·0	978·5	1068·1
22	591·9	662·0	736·0	813·9	895·8	981·4	1071·1
24	594·2	664·4	738·5	816·6	898·6	984·4	1074·2
26	596·5	666·8	741·1	819·2	901·4	987·3	1077·2
28	598·7	669·2	743·6	821·9	904·2	990·3	1080·2
30	601·0	671·6	746·2	824·6	907·0	993·2	1083·3
32	603·3	674·1	748·7	827·3	909·8	996·2	1086·4
34	605·6	676·5	751·3	829·9	912·6	999·1	1089·5
36	607·9	678·9	753·8	832·6	915·5	1002·1	1092·6
38	610·2	681·3	756·4	835·3	918·3	1005·0	1095·7
40	612·5	683·8	759·0	838·0	921·1	1008·0	1098·8
42	614·8	686·2	761·5	840·7	923·9	1010·9	1101·9
44	617·2	688·7	764·1	843·4	926·8	1013·9	1105·0
46	619·5	691·1	766·7	846·1	929·6	1016·9	1108·1
48	621·8	693·6	769·3	848·9	932·4	1019·9	1111·2
50	624·1	696·0	771·9	851·6	935·2	1022·8	1114·3
52	626·5	698·5	774·5	854·3	938·1	1025·8	1117·4
54	628·8	701·0	777·1	857·1	940·9	1028·8	1120·5
56	631·2	703·5	779·7	859·8	943·8	1031·8	1123·6
58	633·5	705·9	782·3	862·6	946·6	1034·8	1126·7

Reduction to Meridian.—*Cont.*

Values of m.

Sec.	24m	25m	26m	27m	28m	29m
	"	"	"	"	"	"
0	1129·9	1225·9	1325·9	1429·7	1537·5	1649·0
2	1133·0	1229·2	1329·3	1433·2	1541·1	1652·8
4	1136·2	1232·5	1332·7	1436·7	1544·8	1656·6
6	1139·3	1235·7	1336·1	1440·3	1548·4	1660·4
8	1142·5	1239·0	1339·5	1443·9	1552·1	1664·2
10	1145·6	1242·3	1342·9	1447·4	1555·8	1668·0
12	1148·8	1245·6	1346·3	1451·0	1559·5	1671·9
14	1152·0	1248·9	1349·7	1454·5	1563·2	1675·7
16	1155·2	1252·2	1353·2	1458·1	1566·9	1679·5
18	1158·3	1255·5	1356·6	1461·6	1570·5	1683·3
20	1161·5	1258·8	1360·1	1465·2	1574·3	1687·2
22	1164·7	1262·2	1363·5	1468·7	1578·0	1691·0
24	1167·9	1265·5	1367·0	1472·3	1581·7	1694·8
26	1171·1	1268·8	1370·4	1475·9	1585·3	1698·6
28	1174·3	1272·1	1373·9	1479·5	1589·1	1702·5
30	1177·5	1275·4	1377·3	1483·1	1592·7	1706·3
32	1180·7	1278·8	1380·8	1486·7	1596·5	1710·2
34	1183·9	1282·1	1384·2	1490·3	1600·2	1714·0
36	1187·1	1285·5	1387·7	1493·9	1604·0	1717·9
38	1190·3	1288·8	1391·2	1497·5	1607·7	1721·7
40	1193·5	1292·2	1394·7	1501·1	1611·5	1725·6
42	1196·7	1295·5	1398·2	1504·7	1615·2	1729·5
44	1199·9	1298·9	1401·7	1508·4	1619·0	1733·4
46	1203·1	1302·2	1405·2	1512·0	1622·7	1737·2
48	1206·4	1305·6	1408·7	1515·6	1626·5	1741·2
50	1209·6	1309·0	1412·2	1519·2	1630·2	1745·1
52	1212·9	1312·4	1415·7	1522·9	1634·0	1749·0
54	1216·1	1315·7	1419·2	1526·5	1637·7	1752·8
56	1219·4	1319·1	1422·7	1530·2	1641·5	1756·8
58	1222·6	1322·5	1426·2	1533·8	1645·2	1760·7

Table of Refractions.

Barometer 30″.
+ when above.
− when below.

Thermometer 50°.
− when above.
+ when below.

App. Alt.	Refr. B. 30″. Th. 50°.	Difference to be allowed for.			App. Alt.	Refr. B. 30″. Th. 50°.	Difference to be allowed for.		
		1′ Alt.	+ 1″ B.	− 1° Th.			1′ Alt.	+ 1″ B.	− 1° Th.
° ′	′ ″	″	″	″	° ′	′ ″	″	″	″
8 0	6 33	·7	13·3	·85	13 0	4 7·2	·32	8·30	·509
,, 10	6 26	·7	13 1	·83	,, 10	4 4·1	·31	8·20	·503
,, 20	6 19	·7	12·8	·82	,, 20	4 1·0	·31	8·10	·496
,, 30	6 12	·7	12 6	·80	,, 30	3 58·1	·29	8·00	·490
,, 40	6 5	·7	12·3	·79	,, 40	3 55·2	·29	7·89	·482
,, 50	5 59	6	12·1	·77	,, 50	3 52·3	·29	7·79	·476
9 0	5 52·6	·6	11·9	·76	14 0	3 49·5	28	7·70	·469
,, 10	5 46·6	·6	11·7	·74	,, 10	3 46·8	·27	7 61	·464
,, 20	5 40·7	·6	11·5	·73	,, 20	3 44·2	·26	7·52	·458
,, 30	5 35·1	·6	11·3	·71	,, 30	3 41·6	·26	7·43	·453
,, 40	5 29·6	·5	11·1	·71	,, 40	3 39·0	·26	7·34	·448
,, 50	5 24·3	·5	11·0	·70	,, 50	3 36·5	·25	7·26	·444
10 0	5 19·2	·5	10·8	·69	15 0	3 34·1	·24	7·18	·439
,, 10	5 14·2	·5	10·6	·67	,, 30	3 27·1	·23	6·95	·424
,, 20	5 9·3	·5	10·4	·65	16 0	3 20·5	·22	6·73	·411
,, 30	5 4·6	·5	10·2	·64	,, 30	3 14·2	·21	6·51	·399
,, 40	5 0	·5	10·1	·63	17 0	3 8·3	·20	6·31	·386
,, 50	4 55·6	·4	9·9	·62	,, 30	3 2·8	·18	6·12	·374
11 0	4 51·2	·4	9·8	·60	18 0	2 57·5	·17	5·98	·362
,, 10	4 47	·4	9 6	·59	19 0	2 47·7	·16	5·61	·340
,, 20	4 42·9	·4	9·5	·58	20 0	2 38·8	·15	5·31	·322
,, 30	4 38·9	·4	9·4	·57	21 0	2 30·7	·13	5·04	·305
,, 40	4 35	·39	9·2	·56	22 0	2 23·3	·12	4·79	·290
,, 50	4 31·2	·38	9·1	·56	23 0	2 16·4	·11	4·57	·276
12 0	4 27·5	·37	9·00	·556	24 0	2 10·2	·10	4·35	·264
,, 10	4 23·9	·36	8·86	·548	25 0	2 4·4	·10	4·16	·252
,, 20	4 20·4	·35	8·74	·541	26 0	1 58·9	·09	3·97	·241
,, 30	4 17·0	·34	8·68	·533	27 0	1 53·9	·08	3·81	·230
,, 40	4 13·6	·34	8·51	·524	28 0	1 49·2	·08	3·65	·219
,, 50	4 10·4	·32	8·41	·517	29 0	1 44·8	·07	3·50	·209

TABLE OF REFRACTIONS.—*Cont.*

App. Alt.	Refr. B. 30″. Th. 50°.	Difference to be allowed for.			App. Alt.	Refr. B. 30″. Th. 50°.	Difference to be allowed for.		
		1′ Alt.	+ 1″ B.	− 1° Th.			1′ Alt.	+ 1″ B.	− 1° Th.
° ′	′ ″	″	″	″	° ′	′ ″	″	″	″
30 0	1 40·6	·07	3·36	·201	60 0	0 33·6	·023	1·12	·067
31 0	1 36·7	·06	3·23	·193	61 0	0 32·3	·022	1·08	·065
32 0	1 33·0	·06	3·11	·186	62 0	0 31·0	·022	1·04	·062
33 0	1 29·5	·06	2·99	·179	63 0	0 29·7	·021	·99	·060
34 0	1 26·2	·05	2·88	·173	64 0	0 28·4	·021	·95	·057
35 0	1 23·1	·05	2·78	·167	65 0	0 27·2	·020	·91	·055
36 0	1 20·1	·05	2·68	·161	66 0	0 25·9	·020	·87	·052
37 0	1 17·2	·05	2·58	·155	67 0	0 24·7	·020	·83	·050
38 0	1 14·5	·05	2·49	·149	68 0	0 23·6	·020	·79	·047
39 0	1 11·9	·04	2·40	·144	69 0	0 22·4	·020	·75	·045
40 0	1 9·4	·04	2·32	·139	70 0	0 21·2	·020	·71	·043
41 0	1 7·0	·04	2·24	·134	71 0	0 20·1	·020	·67	·040
42 0	1 4·7	·038	2·16	·130	72 0	0 18·9	·019	·63	·038
43 0	1 2·4	·036	2·09	·125	73 0	0 17·8	·018	·59	·036
44 0	1 0·3	·035	2·02	·120	74 0	0 16·7	·018	·56	·033
45 0	0 58·2	·035	1·94	·117	75 0	0 15·6	·018	·52	·031
46 0	0 56·2	·033	1·88	·112	76 0	0 14·5	·018	·48	·029
47 0	0 54·3	·032	1·81	·108	77 0	0 13·5	·017	·45	·027
48 0	0 52·5	·030	1·75	·104	78 0	0 12·4	·017	·41	·025
49 0	0 50·6	·030	1·69	·101	79 0	0 11·3	·017	·38	·023
50 0	0 48·9	·029	1·63	·097	80 0	0 10·3	·017	·34	·021
51 0	0 47·2	·028	1·58	·094	81 0	0 9·2	·017	·31	·018
52 0	0 45·5	·027	1·52	·090	82 0	0 8·2	·017	·27	·016
53 0	0 43·9	·026	1·47	·088	83 0	0 7·2	·017	·24	·014
54 0	0 42·3	·026	1·41	·085	84 0	0 6·1	·017	·20	·012
55 0	0 40·8	·025	1·36	·082	85 0	0 5·1	·017	·17	·010
56 0	0 39·3	·025	1·31	·079	86 0	0 4·1	·017	·14	·008
57 0	0 37·8	·025	1·26	·076	87 0	0 3·1	·017	·10	·006
58 0	0 36·4	·024	1·22	·073	88 0	0 2·0	·016	·07	·004
59 0	0 35·0	·024	1·17	·070	89 0	0 1·0	·016	·03	·002

Sun's Parallax in Altitude.

Alt.	0°	12°	20°	30°	33°	39°	42°	48°	51°	57°	60°	66°	69°	72°	75°	78°	81°	84°	90°
Par.	9″	9″	8″	8″	7″	7″	6″	6″	5″	5″	4″	4″	3″	3″	2″	2″	1″	1″	0″

The following table will be found useful for calculating positions by Plane Trigonometry :—

LENGTH IN FEET OF A SECOND OF ARC, OF LATITUDE AND LONGITUDE, ON THE SURFACE OF THE EARTH.

In Latitude.	Length in feet of		In Latitude.	Length in feet of	
	A Second of Arc of Longitude.	A Second of Arc of Latitude.		A Second of Arc of Longitude.	A Second of Arc of Latitude.
			°		
0	101·43	100·76	38	80·03	
1	101·41		39	78·93	
2	101·37		40	77·80	101·17
3	101·29		41	76·66	
4	101·18		42	75·49	
5	101·05	100·77	43	74·29	
6	100·86		44	73·08	
7	100·68		45	71·84	101·26
8	100·45		46	70·58	
9	100·19		47	69·30	
10	99·90	100·79	48	67·99	
11	99·53		49	66·67	
12	99·23		50	65·32	101·34
13	98·85		51	63·96	
14	98·44		52	62·57	
15	97·99	100·83	53	61·17	
16	97·53		54	59·75	
17	97·02		55	58·31	101·42
18	96·50		56	56·57	
19	95·94		57	55·09	
20	95·35	100·88	58	53·60	
21	94·73		59	52·09	
22	94·09		60	50·84	101·52
23	93·41		61	49·30	
24	92·71		62	47·74	
25	91·98	100·94	63	46·17	
26	91·22		64	44·58	
27	90·44		65	42·98	101·58
28	89·62		66	41·37	
29	88·78		67	39·74	
30	87·91	101·01	68	38·10	
31	87·02		69	36·45	
32	86·10		70	34·79	101·64
33	85·15		71	33·12	
34	84·17		72	31·43	
35	83·18	101·09	73	29·74	
36	82·15		74	28·04	
37	81·10				

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